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Evapotranspiration and Watershed Research as Related to Riparian and Phreatophyte Management

An Abstract Bibliography

Miscellaneous Publication No. 1234

Forest Service—U.S. Department of Agriculture

An Abstract Bibliography

Evapotranspiration *and* Water Research *as Related to* Riparian *and* Phreatophyte Management

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Forest Service—U.S. Department of Agriculture

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PREFACE

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INTRODUCTION

Determining actual or potential water losses from vegetation is difficult because of the complexity of the factors affecting evapotranspiration and the many problems involved in their measurement. Though many techniques for determining water losses from vegetation have been developed, the data obtained tend to be inconclusive and difficult to apply in wild-land management. The purpose of this abstract bibliography is to bring together published information that will help land managers and research workers to: (1) Evaluate relations of vegetation to water loss and (2) estimate the probable effect on water yield of manipulating vegetation.

The bibliography emphasizes moist-site vegetation, both phreatophyte and riparian, but watershed and plot studies are included if they can be useful in determining the effect of vegetation management on water yield. The development and use of various kinds of lysimeters are comprehensively reviewed to give a full picture of their value in determining evapotranspiration losses. Methods of estimating or measuring water losses (such as sap-flow instrumentation or the energy-budget approach) have been given full coverage; even though in many cases the studies were carried out on agricultural lands, the methods might be adapted for use with moist-site vegetation.

Articles on the various processes affecting evapotranspiration, including physiological, climatic, and general environmental processes, have been included if they have a direct bearing upon measurement of water loss in phreatophyte and riparian situations.

References which give potential evaporation losses over a wide area, even though essentially written for application to irrigation and water-supply projects, are included if they can be applied either directly or indirectly to evaluating water losses from moist sites.

If the abstract is a direct quotation from the author, a notation to this effect (such as "Auth. abstr.," "Auth. sum.," or "Auth. introd.") follows the text material. In many cases, minor changes have been made in punctuation or in abbreviation.

If, however, the author's material is used in a condensed form or given minor editing in the interest of uniform treatment in this bibliography, this is indicated by the notation "From auth._____".

Frequently, no notation appears after the item. In some cases, the comments are in the form of an annotation prepared by the compiler to inform the reader of the general nature of the subject matter. In

other cases, if the original article did not include a formal abstract or condensed summary suitable for presentation, the compiler prepared a new abstract from the text.

If material is included which clarifies the relationship of the item to other publications, the notation, "Compiler's Note," is used to introduce the discussion. Also this notation is used if an article written in a foreign language is summarized by another writer. The compiler's minor additions to author's abstracts are indicated by brackets.

For a number of the references, neither abstracts nor compiler's notes are given because the title is sufficiently indicative of the material contained in the article.

If a reference is made to another abstract included in the bibliography, the author, date of publication, and item number are given; for example, (Robinson 1959, 81) means that Robinson's article published in 1959 appears in this bibliography as item 81. The references to the Penman, Blaney-Criddle, and Thornthwaite methods of estimating evapotranspiration are not cited in this manner because a full section is devoted to articles on each of these methods.

The references are arranged alphabetically by author within the subject-matter class. If an article is applicable to several classes, a cross reference is given at the end of each appropriate class. If several cross references are given, the more important ones are in boldface type.

An author index gives item numbers. If an author's full name is used in any of the listed citations, it appears in this form in the index, even though only his initials may be used in other citations.

Library List No. 75 (Revised Feb. 1968), "Serial Publications Indexed in Bibliography of Agriculture," published by the National Agricultural Library, U. S. Department of Agriculture, was used in determining the forms of the references wherever possible. Abbreviations in the references follow "American Standard for Periodical Title Abbreviations," published (1966) by the National Clearing House for Periodical Title Word Abbreviations, c/o Chemical Abstracts Service, Columbus, Ohio. At the end of the bibliography is a listing of abbreviations used in the entries.

Most of the articles and publications cited are available in major libraries or are on file in the library of the Phreatophyte Subcommittee, Pacific Southwest Inter-Agency Committee, maintained by the Rocky Mountain Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture, at Tempe, Arizona. All of the material marked "Processed" is on file in this library and may be difficult to find elsewhere.

GENERAL BACKGROUND MATERIAL

DISCUSSIONS OF THE EVAPOTRANSPIRATION PHENOMENON

AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS 1

1966. Evapotranspiration and its role in water resources management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. 66 p., illus.

Discussions of evapotranspiration and the status of research constitute a comprehensive review. Most of the articles are abstracted in this bibliography.

BAUMGARTNER, A. 2

1965. The heat, water and carbon dioxide budget of plant cover: methods and measurements. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 495–512.

This article describes the correlations existing among the water, carbon dioxide, and heat budgets of plant cover, explains the principles of measuring methods, and gives the basic results obtained with different species of plant cover.

BRITISH ECOLOGICAL SOCIETY 3

1963. The water relations of plants. Brit. Ecol. Soc. Symp. 3, London, April 5–8, 1961. Rutter, A. J., and Whitehead, F. H. (eds.). Blackwell Sci. Pub. [London] 394 p., illus.

The British Ecological Society organized a symposium on this topic barely two years after a similar one had been held in Madrid, under the auspices of UNESCO, and a different set of contributors of international reputation was available to sustain the symposium. The Madrid symposium was mainly concerned with the problems of arid lands. This volume complements the report of that symposium in that it lays greater emphasis on temperate vegetation.

This volume provides new information on subjects of fundamental importance to plant water relations, such as evaporation, dew formation, and water movement through soil and plant. In addition, investigations from varied standpoints of the relationship of water balance to growth and development represent a valuable contribution to the understanding of the biological problems involved.

CZECHOSLOVAK ACADEMY OF SCIENCES 4

1965. Water stress in plants. Czech. Acad. Sci. Symp. Proc., Prague, Sept. 30–Oct. 4, 1963. Slavik, Bohdan (ed.). Dr. W. Junk Pub. [The Hague] 322 p., illus.

These proceedings, containing papers contributed to the symposium and authorized recordings of the discussions, survey problems and studies of water deficiency. The publication shows what is known of the problems and where there are gaps in present knowledge. It reports attempts to synthesize present conceptions and to outline the best directions for further work.

DECKER, WAYNE L. 5

1966. Potential evapotranspiration in humid and arid areas. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 23–26, illus.

In general, evapotranspiration includes evaporation from soil and water surfaces and transpiration from plants. Since the evaporative process involves the change of water from liquid to vapor it requires heat of vaporization. Thus it is possible to view evapotranspiration as an energy-transfer mechanism.

Potential evapotranspiration is the product of the atmospheric environment, and the magnitude does not involve the type of surface cover so long as it may be considered "wet." If potential evapotranspiration is an atmospheric property, it has meaning only in terms of the maximum transfer of mass from liquid water to vapor and the maximum dissipation of energy by vaporization at the earth's surface. It does not necessarily follow that the potential evapotranspiration will have a real significance in hydrologic studies or in the solution of problems dealing with the soil-water balance. If the potential evapotranspiration never or seldom occurs, it cannot be directly applied to hydrology or soil-water studies. Briefly, the availability of energy, the net radiative balance, is considered to be the primary factor in determining the magnitude of potential evapotranspiration. The vapor-pressure deficit or the dryness of the air is also important in determining potential evapotranspiration because wind provides the mechanism for mixing within the atmosphere.—From auth. sum.

ECKARDT, F. E. 6

1960. Eco-physiological measuring techniques applied to research on water relations of plants in arid and semi-arid regions. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Reviews of Research. UNESCO Arid Zone Res. [Paris] 15: 139–171.

Although the methodology of research on the water economy of arid zone plants covers a complex of techniques bearing on a great many biological functions and ecological factors, this article is confined, because of the limited space available, to a study of those of immediate interest to research on the actual translocation of water.

The presentation begins with a description of methods for studying the physiological behaviour of isolated plants in relation to water, placing special emphasis on the problems involved in measuring transpiration. After a short discussion of methods of measuring environmental factors, the article considers the question of the water balance of the plant cover. Finally, it mentions briefly certain laboratory devices which, to some extent, reproduce field conditions or enable the main ecological factors round the plant to be varied, while at the same time allowing its physiological reactions to be observed.—From auth. introd.

GARDNER, W. R. 7

1960. Soil water relations in arid and semi-arid conditions. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Reviews of Research. UNESCO Arid Zone Res. [Paris] 15: 37–61.

The underlying principles of soil-water relations have been understood at least qualitatively for many years, and recent research has been directed at obtaining a more nearly quantitative understanding. However, there is still much to be learned of a basic nature concerning the interaction of water with soils and its relation to plant growth. This summary of recent research is intended to give a reasonably complete picture of current concepts and the present state of understanding of soil-water relations; no attempt is made at a complete review of work leading to this understanding. The discussion has been restricted mainly to basic aspects, since the application of the principles is reviewed in some detail elsewhere.—From auth. introd.

HANSEN, VAUGHN E. 8

1966. Evapotranspiration and water resources management. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 12–13.

Broad guidelines and cautions for determination and use of evapotranspiration in water-resource management are discussed. Details of methodology sometimes obscure fundamentals. Reliable estimates of evapotranspiration

are of prime importance because the water used in evapotranspiration is nonrecoverable, and production—and thus the profit—is directly related to the evapotranspiration.

Useful data are essential, but pitfalls in their collection exist. Required reliability and accuracy of estimates of evapotranspiration depend on the use to be made of the data. The most important part of an estimate is the first significant figure. It is important that it be correct. The accuracy of the estimate is no better than the accuracy of the least reliable component. Be sure the estimate is truly representative of the population being studied. Estimates of evapotranspiration must reflect spacial changes of geography, variation of climate, and changes of project management with time. Confidence can be established and estimates improved by comparison with measured values. Be sure "measured" values are without bias. Added confidence can be gained by comparing answers obtained from different methods and by understanding biases and peculiarities of each method. Thus a clear understanding of the unique characteristics of each method used to estimate evapotranspiration is of basic importance in wise water-resource management.—From auth. sum.

KONSTANTINOV, A. R. 9

1966. Evaporation in nature. (Isparenie v prirode. Gidrometeorol. izdatel'stvo [Leningrad] 1963.) Trans. from the Russian by I. Shechtman, 1963. Israel Program for Sci. Trans. 1529 (TT66–51015), 523 p.

This monograph deals with the problems of measuring, computing, and investigating the evaporation regime under natural conditions. An analysis is given of methods used for measuring evaporation from soil, snow, and water surfaces. Methods for investigating turbulent processes are also examined. As a result of the analysis, methods for calculating the evaporation from given gradient measurements are worked out. An evaluation of the change in the evaporation regime and the water balance of the soil with respect to various agricultural and forestation improvement measures is deduced.—From auth. annot.

KOZLOWSKI, T. T. (ED.) 10

1968. Water deficits and plant growth. 2 vol. Academic Press, New York and London. vol. 1, 390 p.; vol. 2, 333 p.

The rapidly proliferating interest in water resources and accelerated research activity on effects of drought on plants indicated the need for this two-volume treatise. Its purpose is to present a comprehensive work on the physical basis of development and control of internal water deficits in plants, the valid measurement of such deficits, and the characterization of various physiological and growth responses of both herbaceous and woody plants to water deficits. The primary concern throughout is with water-stressed plants rather than general water relations of plants which are not undergoing water stress.—From auth. preface.

KRAMER, PAUL J. 11

1969. Plant and soil water relationships: a modern synthesis. McGraw-Hill, N.Y. 482 p., illus.

This book attempts to cover the entire field of soil-plant-atmosphere water relationships in an integrated manner, using modern terminology and concepts. It contains discussions of the properties of water and solutions, cell water relations, soil water, root systems, water and salt absorption and movement through plants, transpiration, the effects of water deficits on plants, and the measurement of plant water stress.

The interrelationships among the processes involved in water movement from soil to roots, through plants, and into the air have been emphasized by use of the Gradman-van den Honert concept. This concept treats water movement through the soil-plant-air continuum as analogous to flow of electricity through a conductor, the rate being determined by the differences

in potentials and resistances in various parts of the system. Although an oversimplification, this approach is useful both in teaching and in research because it permits identification and evaluation of the importance of the various factors affecting water movement at each stage in its progress through the plant.—From auth. preface.

KRAMER, PAUL J., AND KOZLOWSKI, THEODORE T. 12

1960. Physiology of trees. McGraw-Hill, N.Y. 642 p.

Plant-water relations and other physiological processes are thoroughly discussed.

LANGBEIN, W. B., AND ISERI, KATHLEEN T. 13

1960. General introduction and hydrologic definitions. U. S. Geol. Surv. Water-Supply Pap. 1541–A, 29 p., illus.

This general discussion of hydrologic terms includes definitions of the various phrases used in describing water losses.

LEIGHLY, JOHN 14

1937. A note on evaporation. Ecology 18(2): 180–198.

A theory of the dependence of rate of evaporation (into moving air) is elaborated: It is based on the hypothesis of the existence of a laminar boundary layer of air, having a thickness that varies with wind velocity, next to the evaporating surface. Rate of evaporation then becomes equivalent to rate of molecular diffusion of water vapor through this layer. All the terms involved in an expression for rate of diffusion through the boundary layer can be given a rational expression, except thickness of the layer. For small surfaces, such as the transpiring surfaces of plants and evaporimetric surfaces, the thickness of the boundary layer may be expressed as an empirical function of wind velocity and length of the evaporating surface in the direction of movement of the wind. Available experimental data seem to show that this thickness is proportional to a power smaller than unity of the quotient obtained by dividing wind velocity by the linear dimension of the surface, measured in the direction of wind movement.

The theory is used as the basis of a more rigorous definition of "relative transpiration" than has heretofore been formulated. An experimental procedure is described whereby this rigorous "relative transpiration" or its reciprocal, "transpiration resistance," may be obtained. Experimentation directed toward this end must, however, make use of evaporimetric surfaces that are aerodynamically similar to the transpiring surfaces under investigation, rather than of evaporimeters having arbitrarily selected sizes and shapes.—From auth. sum.

LEMON, E. R. 15

1966. Plant factors and transpiration—the plant community. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 17–21, 26, illus.

This paper presents random observations that, in part, stem from relevant studies with which the author has been associated, either directly or indirectly. Topics discussed are: (a) Fluid transport in the plant, (b) vapor transport out of the leaf, (c) vapor transport through the leaf boundary layer, and (d) vapor transport in the bulk air of plant communities.

Plant communities play a role in influencing the diffusive properties of the bulk air between the foliage parts. The community structure thus plays a significant part in influencing its own climate. However, it is not clear how this affects transpiration. As one may suspect, the more dense the community, the less the ventilation. In turn, community bulk-air characteristics will diverge from the ambient climate of the air above the community. Thus, the diffusive properties of the bulk air in the plant community may influence

transpiration not only directly through its ability to carry off the water vapor, but also indirectly by influencing the climate of the community, i.e., the leaf temperature and air temperature.

How the links in the transfer of water are intercoupled is not yet understood, but what they are and some of the factors operating to influence them are pinpointed.—From auth. sum.

LEMON, E. R., GLASER, A. H., AND SATTERWHITE, L. E. 16

1957. Some aspects of the relationship of soil, plant, and meteorological factors to evapotranspiration. Soil Sci. Soc. Amer. Proc. 21: 464–468.

Evapotranspiration is a function of soil, plant, and meteorological factors. Attempts to predict evapotranspiration without considering all pertinent factors can meet with only qualified success. It is found that evapotranspiration is controlled by: Soil moisture tension, physiological factors, the relation of soil moisture of an irrigated area to that of its surroundings, and purely meteorological factors of radiation, wind, air temperature, and humidity. Examples are given of the effects of these factors on measured evapotranspiration.—From auth. abstr.

LULL, HOWARD W. 17

1953. Evapo-transpiration: excerpts from selected references. U.S. Dep. Agr. Forest Serv. Southern Forest Exp. Sta. Occas. Pap. 131, 117 p.

Evapotranspiration, as the link in the hydrologic cycle influenced by vegetation, is as important as it is complex. The purpose of this compilation is to give the reader a bird's-eye view of the subject, letting some of the authorities speak for themselves.

MILTHORPE, F. L. 18

1960. The income and loss of water in arid and semi-arid zones. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Reviews of Research. UNESCO Arid Zone Res. [Paris] 15: 9–36.

This article recapitulates the salient features of water supply and evaporation from the viewpoint of the ecologist, rather than the hydrologist or climatologist. Engineering problems associated with water supply for irrigation or other purposes are beyond its scope.

The crux of the problem is to determine the amount of water which is available to the plant at any one time and the plant's responses to this water and to the evaporation potential. Two approaches are possible: (a) To measure directly and to follow continuously the quantity of water in the relevant volume of soil and (b) to estimate this quantity from a knowledge of the gain and loss by the system. The first approach suffers from the limitations of sheer empiricism, allows little flexibility in either interpretation of the system or extrapolation to other conditions, and assumes that the entire response of the plant to water can be related to the amount of water in the soil. The second approach is favored, as it allows much greater scope and flexibility in application and involves an appreciation of the mechanisms concerned, the discussion of which is the main purpose of this paper.—From auth. introd.

PATRIC, J. H. 19

1967. Evaporation and transpiration. Amer. Geophys. Union Trans. 48(2): 701–707.

This article is primarily a review of recent literature (1936–1966) concerning evapotranspiration, but the subject matter is well related to overall water problems.

PHILIP, J. R. 20

1966. Plant water relations: some physical aspects. Annu. Rev. Plant Phys. 17: 245–268.

A concise review with an extensive bibliography.

RABER, ORAN 21

1937. Water utilization by trees, with special reference to the economic forest species of the north temperate zone. U.S. Dep. Agr. Misc. Pub. 257, 97 p.

This report is a compilation of the major theories, experiments, and contributions regarding water utilization by trees since the late 1800's. After brief discussions of absorption, storage, and physical losses of water, the major problem—water losses by transpiration—is thoroughly covered.

RIJTEMA, P. E. 22

1965. An analysis of actual evapotranspiration. Wageningen Centre for Agr. Pub. and Doc. Agr. Res. Rep. [The Netherlands] 659, 107 p., illus.

The evapotranspiration processes, including meteorological, plant, physiological, and soil physical aspects, are fully discussed. Various prediction methods are considered. The evapotranspiration from grass was measured by 32 lysimeters at Wageningen, The Netherlands.

RIJTEMA, P. E. 23

1966. Evapotranspiration. Wageningen Inst. voor Cult. en Waterhuishouding Tech. Bull. [The Netherlands] 47: 72–90, illus.

The main factors determining the actual evapotranspiration from crops are discussed.

The empirical reduction factor *f* for short grass is mainly determined by the difference in reflection between a short grass surface and open water surface. The factor day-length has little influence on the value of the reduction factor.

For the calculation of the transpiration of crops, a new factor was introduced: the apparent diffusion resistance of the crop. This factor takes into account the geometry of the evaporation surface, as well as the variation in stomatal resistance under influence of light intensity and of the suction in the leaf tissue.

Actual evapotranspiration is calculated with a combined aerodynamic and energy-balance approach, taking into account the reflection coefficient of the crop, the surface roughness in relation to crop height and wind velocity, and the apparent diffusion resistance of the crop.

It is shown that the amount of precipitation intercepted by the crop increases evapotranspiration when the apparent diffusion resistance is not equal to zero. An approach to the evaluation of this effect is given.

The value of the apparent diffusion resistance depends both on light intensity and on suction in the leaf tissue. It appeared that the reduction in transpiration due to short supply of water also depends on temperature, on wind velocity, and on the roughness of the crop.—Auth. sum.

ROBINSON, T. W., AND JOHNSON, A. I. 24

1961. Selected bibliography on evaporation and transpiration. U. S. Geol. Surv. Water-Supply Pap. 1539–R, 25 p.

This publication presents selected references from the United States from the early 1800's into 1958.

ROSENBERG, NORMAN J., HART, HOYT E., AND BROWN, KIRK W. 25

1968. Evapotranspiration—review of research. Univ. of Nebr., Coll. of Agr. and Home Econ., Agr. Exp. Sta. MP–20, 80 p.

Evapotranspiration has been the subject of many review articles. An independent search of the voluminous literature of evapotranspiration is essential

nonetheless to proper development of any research program. This review evaluates, so far as possible, original source materials from the earliest available to the most recent on record.

Aerodynamic methods of evaluating evapotranspiration yield sufficiently accurate results for most situations. Energy-balance techniques for estimating evapotranspiration have proven reasonably accurate in the more humid regions of the country. The Bowen-ratio variants of the energy budget have given good results even, it appears, where advection is considerable.

Empirical and bookkeeping methods will continue to be used in agricultural meteorology and logically so. Where simple measurements are easily available and meteorological data can be applied to such equations, the advantages to the user, particularly in survey and planning work, are great.

Of the modern types of lysimeters in use and in development, precision weighing units appear most able to meet the requirements of micrometeorological research in evapotranspiration. Less expensive are the floating types, i.e., those which actually float in water or some other liquid or which rest on resilient cushions.—From auth. preface and sum.

SLATYER, R. O. 26

1967. Plant-water relationships. Academic Press. London and New York. 366 p., illus.

This book covers all phases of evapotranspiration and water movement.

SUTTON, O. G. 27

1953. Micrometeorology. McGraw-Hill, N.Y. 333 p.

The book covers the most important aspects of the physics of the surface air layer and gives the basis for the methods used in predicting evapotranspiration from climatic relationships.

TANNER, C. B., AND GARDNER, W. R. 28

1969. Actual evapotranspiration as determined from soil-water and canopy characteristics and potential evapotranspiration. Dep. Soil Sci., Univ. of Wisconsin, Madison, Wis., Prog. Rep. to Environ. Sci. Ser. Admin. PB 184791. 43 p.

Water loss from soils supporting vegetation is due to either evapotranspiration or drainage. These two components of the water balance of the crop are the most difficult to either measure or calculate. Both advancement in hydrology and increased water use efficiency require a better understanding of the physics of evapotranspiration under droughty conditions and drainage when the soil is wet. Means of calculating both of these components of the hydrologic balance from primary climate, soil, and plant parameters have been investigated.—From auth. abstr.

THORNTHWAITE, C. WARREN, AND HARE, F. KENNETH 29

1965. The loss of water to the air. *In* Agricultural Meteorology. Waggoner, P. E., (ed). Meteorol. Monogr. 6(28): 163–180, illus.

The general evaporation process is covered thoroughly by full but concise discussions of the aerodynamic sink, the energy-balance approach, and the potential evaporation concept as developed by Penman and Thornthwaite. The Penman, Thornthwaite, and Budyko methods of approximating actual evapotranspiration are considered as having scientific merit. In addition, the methods of direct observation of evapotranspiration, such as by lysimeters and atmometers, are described. Drawings of the Thornthwaite potential evaporimeters are included.

UNESCO 30

1958. Climatology and microclimatology. Canberra Symp. [Canberra, 1956] Proc. UNESCO Arid Zone Res. [Paris] 11, 355 p. illus.

The program for this symposium emphasized the important role of the

heat and moisture balance in climatology. In addition to two sessions directly on these subjects, the others, on such questions as microclimate of man and animals, modification of microclimate, and the interrelations of climatic elements and flora and fauna, all dealt with problems which are most easily approached through knowledge of the heat and moisture balance. This symposium was also concerned with the special field of microclimatology, for studies of the heat and moisture balance must, of necessity, take us into the field of small-scale climates.

The matter of instrumentation and observations is basic, but it is not discussed directly. Instruments for microclimatic observations and for detailed studies of the heat and moisture balance are not widely available. Moreover, our techniques of using them in order to obtain the most meaningful results are not always correct. In order to develop our understanding of climatology and to give it the vitality which must come from a sound physical approach, it is necessary that the development of adequate instrumentation, the collection of reliable observations, and the formulation of acceptable theory proceed hand in hand.—From introd. remarks.

UNESCO 31

1960. Plant-water relationships in arid and semi-arid conditions. Reviews of Research. UNESCO Arid Zone Res. [Paris] 15, 225 p., illus.

At its 13th session (Karachi, November 1957), the Advisory Committee on Arid Zone Research, set up to assist UNESCO in the collection and dissemination of scientific information resulting from studies of arid zone problems, recommended the compilation of a review of research on the relationships between plants and water under arid and semi-arid conditions. This was planned to serve as background material for the symposium held in Madrid in 1959.

UNESCO 32

1961. Plant-water relationships in arid and semi-arid conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16, 352 p., illus.

This volume contains 36 papers which were presented at the symposium and a short summary of the discussions.

UNESCO 33

1965. Methodology of plant eco-physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25, 531 p., illus.

Eco-physiology, according to the proceedings of the Montpellier symposium, deals with all relationships between living beings and their physical and biotic environment. It thus embraces not only the study of the adaptive, structural, and functional features which link the individual plant or animal to its specific environment but also the study of all forms of transfer and transformation of energy and mass connected with the dynamics of the ecosystem.

Until recently, because of a lack of adequate techniques, plant eco-physiology was almost exclusively concerned with the study of the behaviour of the individual plant. However, as a result of progress in metrology and data processing, research on plant communities or whole ecosystems is coming within the range of possibility. In the present volume, therefore, special emphasis has been laid upon the description of methods enabling the study of the physiological behaviour of the plant cover considered as a whole.—From chairman's sum.

Van Wijk, W. R., and De Vries, R. D. 34

1954. Evapotranspiration. Neth. J. Agr. Sci. [Wageningen] 2(2): 105–119.

The existing methods of calculating evapotranspiration are discussed. No method based on monthly temperature can be expected to give reliable results for different regions. The temperature of the air lags behind solar radiation at moderate and high latitudes; therefore, if periods with the same temperature are compared, the amount of energy available for evaporation in the spring is quite different from that available in the autumn. For the Netherlands, for instance, this difference amounts to nearly 300 percent between the two months of March and November, with average temperatures of 5.0° and 5.4° C., respectively. Further discrepancies occur in the case of cold or warm ocean currents, and low temperature owing to elevation.

The energy available for evapotranspiration can be calculated by applying the theory of heat exchange (including radiation) to a wet body of the same shape as the vegetation cover. Actual evapotranspiration will be smaller than the calculated maximum value by a factor depending on the physiology (not the morphology) of the plants.—From auth. abstr.

WANG, JEN YU, AND BARGER, GERALD L. 35

1962. Bibliography of agricultural meteorology. Univ. of Wisc. Press, Madison, Wisc. 673 p.

Probably the most comprehensive and accurate listing of publications in agricultural meteorology ever brought together, this bibliography contains more than 11,000 references, mostly to current literature but including classic works. Coverage is world-wide, including papers that were written in more than 30 languages; translated or transliterated as necessary, these are included in their original forms as far as possible.

Agricultural meteorology in this book includes the nature of the atmosphere and solar radiation and the effects of both upon plants and animals; the interchange of energy and moisture that takes place at the earth's surface; the atmosphere to be found in surface layers of soil and water; the factors governing micro-climate, the origin, growth, and development of plants and animals, and the processing and distribution of their products.—From book jacket.

See also 677–686.

RELATIONSHIPS BETWEEN EVAPOTRANSPIRATION AND WATER RESOURCES

General Watershed Areas

ADAMS, FRANK, EWING, PAUL A., AND HUBERTY, MARTIN R. 36

1947. Hydrologic aspects of burning brush and woodland-grass ranges in California. Calif. State Board of Forest. 84 p., illus.

Reports of research summarize knowledge of the effect of vegetation cover on transpiration and runoff.

COLMAN, E. A. 37

1953. Vegetation and watershed management. The Ronald Press Co., N. Y. 412 p., illus.

This book is an original work of synthesis which provides new background for those concerned with the management of cropland, of forest and range, and of water. Its theme is water as a product of the land. Bringing together, for the first time in one setting, the findings of the many sciences that bear on vegetation management in relation to water yield, it presents a critical account of all significant research in this relationship. It also discusses the many complex problems of putting research findings into practice.

The key relationship investigated is that of vegetation management to water control and supply. Plant life, including forests, grasses, and agricultural crops, influences the rate at which rain and melting snow can seep into the soil and groundwater reservoirs; it slows the runoff of water and

checks erosion of soils. Because the quality, timing, and quantity of water delivered from many watersheds are often not satisfactory, much study has been given in recent years to the possibility of "managing" vegetation to improve the way water comes off the land. The author analyzes the significant experimental work done in the United States and abroad that bears on vegetation management as it affects the control of water on the land. He also emphasizes the great importance of the opportunity of riparian and phreatophytic vegetation to utilize vast amounts of water along flowing streams and rivers and from the ground water table.—From foreword.

COOPERRIDER, CHARLES K., AND SYKES, GLENTON G. 38

1938. The relationship of streamflow to precipitation on the Salt River watershed above Roosevelt Dam. Ariz. Agr. Exp. Sta. Tech. Bull. 76, 69 p., illus.

The purpose of this publication was to present the circumstances surrounding runoff from its origin in precipitation on the Salt River Basin, Ariz., to the flow discharged by the Salt River. Detailed discussions are included of precipitation and streamflow records and the relationship of vegetation to the difference between precipitation and water yield.

DORTIGNAC, E. J. 39

1965. Forest water yield management opportunities. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 579–592.

Real needs exist to improve the quantity, timing, and quality of water yielded from many forested and nontilled watersheds. The role of watershed management in meeting these needs is described. What can be done, where it appears most needed, and some methods of doing it are presented. Modification and alteration of vegetation, supplemented by snow fences and by mechanical and chemical treatments, offer some promising possibilities. The practicality of these treatments is indicated by some estimated costs, which are compared with costs of alternative methods.

It has been estimated that about one-fourth of the water now used by phreatophytes in the 17 Western States—amounting to more than 6 million acre-feet of water—could be saved. This estimate appears overly optimistic, particularly in view of the increasing importance of fish, wildlife, recreation, and natural beauty. Removing trees along the borders of streams might raise the water temperature beyond the safe limit for game fish. Streamside and lakeside trees are important for wildlife, recreation, and esthetic values. Removing all trees over a large or extensive area usually is not sound management and therefore is unlikely to gain public acceptance. Reducing the vegetation mass by thinning, defoliation, and other means during critical periods may be more acceptable.—From auth. abstr. and sum.

FLETCHER, H. C., AND RICH, L .R. 40

1955. Classifying southwestern watersheds by their water yields. J. Forest. 53(3): 196–202, illus.

Watersheds in the Southwest are affected by elevation, soil, temperature, and direction of prevailing precipitation more than those in any other area in the United States. These factors, plus topography and vegetation, control the annual water yield and may be classified within that context. Evapotranspiration by vegetation cover may be effective in classifying these areas. In summer, evapotranspiration exceeds the precipitation, while in the winter, because of plant dormancy and increased rainfall, the water supply produces a surplus.

In combining evapotranspiration with other factors noted, water-yield areas may be classified as high-, intermediate-, or low-yield areas. This concept of watershed classification based on precipitation and potential evapotranspiration provides a practical approach to many problems en-

countered by watershed managers in determining the type of watershed management most logical for the different parts of the Southwest.

KITTREDGE, JOSEPH, JR. 41

1958. Forest influences. McGraw-Hill Book Co., N. Y. 349 p., illus.

This book fully covers the influences of woody vegetation on hydrology and water yield and emphasizes the basic physical processes involved in these influences.

KRAMER, PAUL J. 42

1952. Plant and soil water relations on the watershed. J. Forest. 50(2): 92–95.

Trees and other vegetation affect soil moisture indirectly by modifying interception, evaporation, and the soil conditions controlling infiltration, but their most important effect is direct removal of water by transpiration. Transpiring vegetation removes water in the range from field capacity to permanent wilting.

Plants of different species have widely different transpiration rates, but leaf structure is not a reliable indicator of transpiration rates because some plants with thin leaves have lower rates than other plants with thick, heavily cutinized leaves.

There are large seasonal variations in transpiration, maximum water loss probably occurring about the time maximum leaf area is attained. Midwinter transpiration of pines seems to be nearly as low as that of deciduous species.

Shallow-rooted species usually remove less water than deep-rooted species, especially on deep soils. Shallow-rooted species are therefore preferable on watersheds where water yield is a primary consideration.—From auth. sum.

LASSEN, LEON, LULL, HOWARD W., AND FRANK, BERNARD 43

1952. Some plant-soil-water relations in watershed management. U. S. Dep. Agr. Circ. 910, 64 p., illus.

This publication was prepared to aid land managers, engineers, hydrologists, and others in providing adequate information on how man's treatment of the land affects watershed functions. The publication includes information on the influences of vegetation on retention storage, the soil as a storage reservoir, and soil-water movement and temporary storage. The application of this information to watershed management also is included.

NATIONAL SCIENCE FOUNDATION 44

1965. International symposium on forest hydrology. Sopper, William E., and Lull, Howard W., (eds.). Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug 29–Sept. 10, 1965. Pergamon Press, N. Y. 813 p., illus.

Many of the articles cover phases of watershed management, water-yield improvement, and evapotranspiration losses.

TROXELL, HAROLD C. 45

1953. The influence of ground-water storage on the runoff in the San Bernardino and eastern San Gabriel Mountains of southern California. Amer. Geophys. Union Trans. 34(4): 552–562, illus.

The steep and rugged mountains of southern California contain considerable ground-water storage. A large portion of the runoff is seepage from this storage. The variations in runoff distribution depend on the geology, physiography, and soil cover of these mountain areas.—Auth. abstr.

TROXELL, H. C., AND STAFFORD, H. M. 46

1949. Natural water losses in mountain drainage areas of southern California. Amer. Geophys. Union Trans. 30(5): 752–758, illus.

For 25 small mountain drainage areas of southern California, natural water losses are shown to vary with basin altitude and with estimated absorptive and retentive characteristics of the drainage areas. Among other relationships demonstrated is the increase of annual natural water loss with increased annual precipitation to an optimum, beyond which the loss is about uniform regardless of the increased precipitation.—Auth. abstr.

U. S. SENATE 47

1960. Water resources activities in the United States. Evapotranspiration reduction. U. S. Congr. 86th, 2d Sess. Selec. Comm. on Nat. Water Resour. Comm. Print 21, 42 p. illus.

Part I summarizes the problem of phreatophytes and their consumptive waste of water. Specific data on the distribution and extent of phreatophytes are available for only a few river basins. More data are available on the distribution, extent, and rate of infestation of saltcedar than of any other species. Tabulated data are given for river-basin areas of the Western United States for which phreatophyte distribution and extent are known. The data include acreage of infestation, estimated annual water use in acre-feet, year of survey or estimate, and principal species of phreatophytes in each river basin or valley

Part II concerns vegetation management and water yields in the 17 Western States. It includes summaries of research studies of different vegetation types to determine possibilities of increased water yield following management of vegetation. It also includes cover-type maps and a table giving estimates of present and potential water yield.

Forest and Grassland Vegetation

BISWELL, HAROLD H. 48

1968. Water control by rangeland management. *In* Water for Peace: International Conference on Water for Peace—May 23-31, 1967. U. S. Govt. Print. Off., Washington, D. C. 2:740–746.

Man can regulate rangeland water by controlling the intensity and season of grazing and by keeping livestock off areas highly susceptible to compaction when the soil is wet. Where the soil is sufficiently deep and precipitation is in excess of that used by the plants, water runoff can be increased by replacing deep-rooted species (such as shrubs and trees) by more shallow-rooted species (such as desirable grasses and forbs). If the precipitation is less than 18 inches annually, the operator may not be able to increase runoff to any appreciable extent. Where soils are especially erodible and rainfall is relatively high, runoff and erosion may be lessened by planting deep-rooted plants, such as trees, to increase water storage capacity.—From auth. abstr.

CROFT, A. R., AND HOOVER, M. D. 49

1951. The relation of forests to our water supply. J. Forest. 49(4): 245–249.

The future is crowding us with challenging problems in resource management. None of these is more important than the problem of sustaining a usable water supply. On forested lands timber production is so closely allied with the regulated yield of pure, clean, sediment-free water that the forestry profession must assume responsibility for water management, as well as for timber management, in order to discharge its obligation to society.

To do this three things are necessary: (1) The forestry profession must clearly recognize and assume responsibility for management of water from forested lands; (2) the job of managing the water supply from forested lands must be integrated with forest management; and (3) forestry schools must give sufficient instruction in the hydrology of forested lands to prepare

foresters to assume responsibility for water management as part of their jobs as forest managers.—From auth. sum.

GOODELL, B. C. 50

1965. Watershed treatment effects on evapotranspiration. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 477–482.

Evapotranspiration from watersheds depends on spatial and temporal confluence of water and thermal energy at watershed surfaces. Radiant energy is the main source of the heat of evaporation. For any mass of vegetation per unit of land area, evapotranspiration should be maximum when plant substance is most uniformly distributed throughout the growing space. Canopy interception of precipitation and radiation and transport of soil water to transpiring surfaces are then at a maximum.

Forest manipulation that causes heterogeneity in canopy and root distribution, as by partial clearing, should tend to minimize evapotranspiration. To be effective, persistent discontinuities must be produced in the canopy (with respect to its role as receptor for precipitation and radiant energy) or in the root network (as an absorber of soil water) or both. Substitution of vegetation of shallower root or canopy depth or both, longer dormant season, or lower transpiration ratio are other means by which watershed management can reduce evapotranspiration.—From auth. abstr.

MCGINNIES, WILLIAM G., MCCOMB, ANDREW L., AND FLETCHER, JOEL E. 51

1963. Role of watersheds and forests in the arid west. *In* Aridity and Man. Amer. Ass. Advance. Sci. Pub. 74: 277–307.

This article discusses the problems of increasing streamflow from watersheds. It considers snow as a streamflow source, interception of rain, evaporation and transpiration losses, phreatophyte problems, vegetation and floods, management to increase yields, flood control, wind erosion and shelterbelts, water erosion and sedimentation, and research in forest-management problems.

RICH, L. R. 52

1952. Forest and range vegetation. Amer. Soc. Civil Eng. Trans. 117: 974–990, illus.

Consumptive use of water by forest and range vegetation depends primarily on climatic and watershed conditions and on water availability. There are few areas in the West in which unlimited water is available for full potential consumptive use. The ability of plants to grow and use water is greatest in summer and least in winter. Actual water use is dependent on growing conditions when moisture is available. The availability of moisture depends on the distribution of precipitation and the moisture held in the soil for use during periods of drought.

Water use in the semidesert grassland zone was 92 percent of the precipitation for perennial grasses and 98 percent for winter annuals; it was 89 percent of the precipitation lost from bare soil by evaporation. Consumptive use of water in the chaparral zone was 81 percent of the precipitation for grasses and 84 percent for shrubs; it was 78 percent of the precipitation lost from bare soil by evaporation. The use on watersheds in the mixed grassland-chaparral zone ranged from 90 percent to 95 percent of the precipitation on four adjacent watersheds, depending on soil type and depth of soil. Water use on forested watersheds has varied from 77 percent to 90 percent of the rainfall, depending on depth of soil and slope.

A method that appears suited to determining consumptive use of water by forest and range vegetation is to divide the water year into four periods—(1) soil moisture recharge, (2) water surplus, (3) soil moisture utilization, and (4) water deficit—and to consider each period separately. Vegetation

or evaporation from bare soil can always use more water than falls as precipitation during the summer period in the Southwest, and consumptive use is dependent on total precipitation less the small amount of surface runoff that results from summer thunderstorms.—From auth. sum.

SINCLAIR, J. D. 53

1960. Watershed management research in southern California's brush covered mountains. J. Forest. 58(4): 266–268, illus.

This article discusses the objectives of the San Dimas Experimental Forest in California, and some of its projects. Lysimeter results show that infiltration of rainfall into the soil under grass, shrubs, and pine varies from two to more than three times that into bare soil. Evapotranspiration during each dry season exhausted all available moisture in the 6 feet of soil under the shrubs and pine.

Detailed records of rainfall, soil moisture, and rainfall interception from the 875-acre Monroe Canyon showed that 15 inches of the rainfall, or more than half, were lost annually by evapotranspiration.

WOODS, LOWELL G. 54

1966. Increasing watershed yield through management. J. Soil Water Conserv. 21(3): 95–97, illus.

This article reviews some of the research being done and management practices being tested in an effort to increase and regulate water yield from mountain watersheds in National Forests in the West.

ZON, RAPHAEL 55

1912. Forests and water in the light of scientific investigation. *In* U. S. National Waterways Commission Final Report Append. 5, U. S. Congr. 62d, 2d Sess. Senate Doc. 469: 205–302, 1912. (Reprinted in 1927 with revised bibliography, 106 p., illus.)

This paper contains much information on what were called "well-established scientific facts" about the relation of forests to water supply. The general conclusions were that forests increase precipitation and streamflow, promote the flow of springs, and decrease erosion in spite of their heavy use of water through transpiration. The paper summarizes fully the results of extensive research carried on in Germany during the 1870's and 1880's (von Höhnel 1879, 131).

Phreatophyte and Riparian Areas

BITTINGER, MORTON W., AND STRINGHAM, GLENN E. 56

1963. A study of phreatophyte growth in the lower Arkansas River Valley in Colorado. Colo. State Univ., Civil Eng. Sect. CER63MWP–GES6, 31 p. Processed.

A field survey of phreatophytic growth in the bottomland area of the Arkansas River Valley between La Junta and Las Animas, Colo., was conducted in 1962. Tree and shrub growth was classified into five vegetation types, determined from 1957 aerial photographs of the approximately 3,660 acres of phreatophytic trees and shrubs. An increase in area of tree and shrub growth occurred between 1936 and 1957, averaging approximately 50 acres per year; density also increased, primarily because of saltcedar encroachment into the cottonwood stands. About 83 percent of this plant growth enjoys a water table at less than 5 feet below the surface during the growing season.

An estimated 15,000 ± 3,000 acre-feet of water is consumed annually by phreatophytes within the study area; 11,000 acre-feet of this is consumed because of tree and shrub growth. These figures were arrived at through calculations based upon earlier studies by Blaney (1961, 552), Gatewood et al (1950, 364), and Robinson (1958, 80).—From auth. sum.

BLANEY, HARRY F. 57

1933. Consumptive use of water by native plants growing in moist areas in southern California. Introduction and summary. *In* Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 19–25, illus.

The first chapter of the report published by the California Department of Public Works contains a summary and the conclusions obtained from a cooperative study carried on by several agencies in southern California (Calif. Dep. Public Works 1933, 59). Young (1933, 151) compared use of water by various species of plants found in moist or wet areas. These were grown in tanks with the water table maintained at 1 foot, 2 feet, or 5 feet below the surface. Taylor and Nickle (1933, 341) reported riparian water losses in Coldwater Canyon near San Bernardino, Calif. Blaney (1933, 375) reported on the attempt to correlate evaporation data collected from various types of evaporation pans. Troxell (1933, 87) reported on studies made of the ground-water situation along the Santa Ana River.

CALIFORNIA DIVISION OF WATER RESOURCES 58

1930. Rainfall penetration and consumptive use of water in Santa Ana River Valley and Coastal Plain. Calif. Dep. Public Works Div. Water Resour. Bull. 33, 162 p., illus.

At the request of the State Engineer of California, a cooperative investigation was started in December 1927 by the Division of Agricultural Engineering, Bureau of Public Roads, U. S. Department of Agriculture, to determine the disposition of rainfall on the valley floors of the Santa Ana River area in Orange, Riverside, and San Bernardino Counties, Calif. Part I is concerned with moisture penetration and with losses from brush and other native dryland vegetation. (Blaney and Taylor 1930, 253). Part II considers evaporation and transpiration losses from species common in moist areas. (Blaney and Young 1930, 143).

CALIFORNIA DIVISION OF WATER RESOURCES 59

1933. Water losses under natural conditions from wet areas in southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44, 176 p., illus.

The bulletin is in two parts. Part I reports investigations made by the Division of Irrigation, Bureau of Agricultural Engineering, U. S. Department of Agriculture, dealing with the disposal of water by evaporation and transpiration in various parts of southern California. Part II reports investigations made by the Water Resources Branch, Geological Survey, U. S. Department of Interior, dealing with loss of water from the Santa Ana River in lower Santa Ana Canyon. The investigations were made cooperatively with the Division of Water Resources, California Department of Public Works.—From foreword.

CAMPBELL, C. J. 60

1970. Ecological implications of riparian vegetation management. J. Soil Water Conserv. 25(2): 45–52, illus.

Managing riparian vegetation in the Southwest to increase water yield may require selective clearcutting rather than complete removal of riparian plants to maintain a biological balance and thus prevent thermal pollution, channel erosion, and destruction of aquatic and wildlife habitats.—Auth. abstr.

DEBLER, E. B. 61

1937. Valley consumptive use. Amer. Geophys. Union Trans. 18(2): 532–536.

Valley consumptive use represents the total water loss from a valley area

by evaporation and transpiration, excepting dew, frost, fog, or the amount retained within the plant stem. Using Mesilla Valley, N. Mex., as an example, the article graphs the total losses as 4.24 acre-feet per irrigated acre and 2.87 acre-feet per acre of total valley area from 1927 through 1936. Results were obtained by the inflow-outflow method.

FLETCHER, HERBERT C., AND ELMENDORF, HAROLD B. 62

1955. Phreatophytes—a serious problem in the west. *In* Water, U. S. Dep. Agr. Yearb. of Agr. 1955: 423–429.

Phreatophytes occupy about 15 million acres of land in the Western States. These plants form a definite group but do not belong to any specific family. Their common characteristic is their heavy use of a scarce supply of water. As a general rule, the shallower the water table, the higher the rate of use. The depth to the water table controls the occurrence and growth of most species.

Few studies have directly demonstrated how much water could be saved from evapotranspiration loss by removal and replacement of phreatophytes. The actual amount of water saved for use elsewhere by removing the phreatophytic vegetation is still largely a matter of conjecture.

To recover the water, the vegetation must be removed or the water supply must be taken from it. Removal of the vegetation by mechanical means, burning, chemical sprays, or other methods generally is only temporary if other conditions are unchanged. Permanent control can be achieved only when the water supply is removed from the plants by lowering the water table, piping the water across the area, or cutting off the supply from above.

HORTON, J. S. 63

1959. The problem of phreatophytes. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8-13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 48: 76–82.

Phreatophytes occupy large areas along the streams and rivers and on the flood plains of the Southwest. These plants consume water that could be put to better use. Also, the heavy stands of phreatophytes often clog the flood channels.

Five-stamen tamarisk (*Tamarix pentandra* Pall.) is a particularly aggressive species throughout the Southwest. Because of its high water use, adaptability to flood-plain conditions, and rapid spread, this species has created a particularly pressing problem.—From auth. sum.

HORTON, JEROME S. 64

1966. Problems of land management in the various phreatophyte zones. *In* Vegetation Management on Flood Plains and Riparian Lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66–3 Meet., Albuquerque, N. Mex., Aug. 30, 1966. p. 1–6. Processed.

Water shortages in the West began to become apparent about the same time that tamarisk (an introduced ornamental) began to spread aggressively along the major flood plains. There is increasing awareness of problems not only of plant eradication but also of land management for proper use of all resources of the areas occupied by phreatophytes.

In mountainous areas of the Southwest, streams and water courses have a wide variety of vegetation types, which depend on amount of flowing water, elevation, and amount and character of alluvial deposits. Removing shade along these streams will increase water temperature, which will create greater evaporation losses, and these may not be compensated in full by reduced transpiration from fewer trees. Many of the areas along the streams have potential use for recreational development, even where there is no fishing.

HORTON, J. S., ROBINSON, T. W., AND MCDONALD, H. R. 65

1964. Guide for surveying phreatophyte vegetation. U. S. Dep. Agr. Agr. Handb. 266, 37 p., illus.

Knowledge of the extent and nature of the vegetation cover is needed as a basis for planning treatments of the vegetation and estimating potential water savings and other effects. Surveys of the vegetation require an economical sampling scheme that can be repeated and will yield data that are precise enough to be reliable. Such a scheme is described, and the seven steps necessary in a proper survey are explained.—From auth. sum.

LOWRY, ROBERT L. 66

1952. Consumptive use of water. Special case in the Rio Grande Basin. Amer. Soc. Civil Eng. Trans. 117: 1014–1023, illus.

The case of the El Paso (Texas)—Juarez (Mexico) section of the Rio Grande Valley is presented to illustrate the proportion of available water that was lost because of the natural channel conditions and to indicate how losses were reduced by storage, channel rectification and improvement, drainage and canal lining, and control of phreatophytes.

MOWER, R. W., HOOD, J. W., CUSHMAN, R. L., BORTON, R. L., AND GALLOWAY, S. E. 67

1964. An appraisal of potential ground-water salvage along the Pecos River between Acme and Artesia, New Mexico. U. S. Geol. Surv. Water-Supply Pap. 1659, 98 p., illus.

This paper reviews studies of water consumption by phreatophytes, such as saltcedar, saltgrass, sacaton, and mesquite. In addition, estimates were made of the amounts of water that might be salvaged by eradication of saltcedar. Four methods of quantitative determination of consumptive use were used: Extrapolation of rates of water use from other areas, inflow-outflow method, pumping-well analogy method, and transpiration-well method. It was concluded that, if the saltcedar were eradicated, phreatophytic grasses encouraged to grow, and nonartesian water levels controlled, the use of water by evapotranspiration in the phreatophyte area would be about 45,000 acre-feet per year, as opposed to a potential 170,000 acre-feet if saltcedar growth continues uncontrolled.

MUCKEL, DEAN C. 68

1966. Phreatophytes—water use and potential water savings. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 92(IR 4): 27–34, illus.

Salvage of water consumed by phreatophytes of low economic value has long been considered, and increasing emphasis is being placed on this source of water in the arid and semiarid West. Evaluation of potential savings in water use requires that water use be estimated under present and modified conditions. Although the totals given for water use by phreatophytes are impressive and indicate that large quantities of water are being wasted, there is danger of oversimplification when it comes to salvaging the water and converting it to a beneficial use. Three means of salvage are mentioned: (1) Removal or destruction of the phreatophytes by mechanical or chemical means, (2) lowering the water table or diverting the streamflow, and (3) substituting plants of high economic value.

MUCKEL, DEAN C., AND BLANEY, HARRY F. 69

1946. Water losses in the Santa Ana River Canyon below Prado Dam, California. U. S. Dep. Agr., Soil Conserv. Serv., Div. of Irrig. and Water Conserv. 64 p., illus. Processed.

This report covers the investigations made by the Division of Irrigation and Water Conservation, Soil Conservation Service, U. S. Department of Agriculture, during 1944 and 1945. It includes an estimate of consumptive use of water in the Santa Ana River Canyon, Calif., between Prado Dam

and Yorba Bridge, a discussion of the variations of evaporation and transpiration which might be expected owing to changes in climate and changes in the vegetal cover of the valley floor, an estimate of the amount of water being consumed annually by non-economic plants which can be feasibly salvaged and converted to beneficial use during the irrigation season, and a discussion of the conditions necessary to permit salvage of the water and a method by which it might be accomplished. Data and information are presented on the rate of evaporation from soils and free water surfaces; rates of water use by plants, both cultivated and native; ground-water levels; the area and extent of water-using lands; and the effect of Prado Dam on the future vegetal cover of the valley floor.—From auth. introd.

NATIONAL RESOURCES COMMITTEE 70

1938. Regional planning, Part VI—Upper Rio Grande. 566 p., illus.

This extensive report on the water problems of the Rio Grande drainage above Fort Quitman, Tex., covers in great detail all phases of water supply, irrigation and other needs, flood control, water quality, etc. The section, Water Utilization, by Blaney, Ewing, Israelsen, and others (1938, 362) is abstracted separately because of data given on research studies on phreatophyte water losses.

NATIONAL RESOURCES PLANNING BOARD 71

1942. The Pecos River joint investigation. Reports of the participating agencies. 407 p., illus.

This report covers problems of water supply, irrigation and other needs, flood control, salinity, etc., for the Pecos River drainage in New Mexico and Texas. Another abstract covers consumptive use and the studies carried on to make more accurate determination of water losses (Blaney, Ewing, Morin, and others. 1942, 142).

PHREATOPHYTE SUBCOMMITTEE, PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE 72

1952. Symposium on phreatophytes. Amer. Geophys. Union Trans. 33(1): 57–80, illus.

The various aspects of the increasing water losses by flood-plain vegetation are discussed in detail in a series of papers.

PHREATOPHYTE SUBCOMMITTEE, PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE 73

1957. Symposium on phreatophytes, Pac. Southwest Reg. Meet., Amer. Geophys. Union, Sacramento, Calif., Feb. 14–15, 1957. 52 p., illus. Processed.

The papers in this review of the phreatophyte problem bring the situation up to date.

PHREATOPHYTE SUBCOMMITTEE, PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE 74

1961. The phreatophyte problem. *In* Pacific Southwest Inter-Agency Committee Minutes of the 61-4 Meeting, Las Vegas, Nev., Nov. 29, 1961. p. 4-58, illus. Processed.

These discussions stress accomplishments of the various agencies dealing with phreatophytes and emphasize needed research.

PHREATOPHYTE SUBCOMMITTEE, PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE 75

1966. Vegetation management on flood plains and riparian lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66–3 Meet., Albuquerque, N. Mex., Aug. 30, 1966. 57 p., illus. Processed.

More stress is being placed on the management of phreatophyte and

riparian zones for multiple use instead of water salvage alone. The papers outline the status of research and future needs in research.

ROBINSON, T. W. 76

1952. Phreatophytes and their relation to water in western United States. Amer. Geophys. Union Trans. 33(1): 57–61, illus.

Phreatophytes cover about 15 million acres in the 17 Western States and may waste as much as 20 to 25 million acre-feet of water into the atmosphere annually. Many variable factors affect the growth of the plants and their use of water, but knowledge of them is limited. The water used by these plants probably represents the largest source of reclaimable water in the arid Western United States. Obviously, it is not possible to salvage all the water wasted, but the potentialities and the rewards of success are sufficient to warrant thorough investigation and study of the problem of ground water salvage.

One way of reducing waste would be to destroy the vegetation. Destroying some species of vegetation, however, is not a simple task. Saltcedar is particularly difficult to destroy, and attempts to kill the cover by burning, mechanical removal, or use of herbicides have not been completely successful.

Even when the plant is successfully destroyed, there is a question whether a saving of water will be effected under certain conditions. In areas where capillary fringe is at or near the land surface, the rise of the water table resulting from the decrease of evapotranspiration may bring the water so close to the surface that the discharge by soil evaporation will increase and possibly equal the former discharge by evapotranspiration. On the other hand, where the water table is sufficiently deep that the capillary fringe does not extend to the land surface and the plants intercept only a part of the ground water as it moves down gradient to a point of ground-water discharge, the method should be quite successful.

Lowering the water table in the area of evapotranspiration discharge, either by pumping or by drainage, is another method of reducing waste. To be successful, however, the drainage should be rapid so that plants will die for lack of water; otherwise, the plant roots will keep pace with the declining water table and keep the plant alive until conditions are again stable.

The efficiency of use of ground water may be increased by substituting, in the area of discharge, plants having higher economic value. Forage crops, particularly alfalfa and grasses, seem best adapted for this purpose.—From auth. sum.

ROBINSON, T. W. 77

1957. The role of phreatophytes in the hydrology of arid regions. *In* Congreso Geologico Internacional, XX Sesion, Cuidad de Mexico, 1956. Sección IV. Mexico, D. F. p. 77–92, illus.

The vegetation of arid regions may be divided, on the basis of the source of its water supply, into two general classes, xerophytes and phreatophytes. Xerophytes are the more extensive group. Phreatophytes are more closely related to, and have greater effect on, the water available for man's use. In addition to their effect on water supply, phreatophytes may grow so densely along streams as to increase the flood hazard by choking the normal overflow channels.

The occurrence of phreatophytes may be used as a guide to indicate not only the presence of ground water but also its approximate depth and quality. Using large quantities of water and being mostly of low economic value, these plants waste large quantities of ground water through the process of transpiration. This draft on the ground-water reservoirs of the arid regions depletes an already inadequate water supply. Much of the wasted water can be salvaged and therefore conserved by methods that will put it to a higher beneficial use.—From auth. abstr.

ROBINSON, T. W. 78

1958. The importance of desert vegetation in the hydrologic cycle. *In* General Assembly of Toronto, Sept. 3–14, 1957, Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 44: 423–430, illus.

In regions of short water supply, the use of water by natural vegetation is highly competitive with its use by man. Transpiration by plants is an important part of the hydrologic cycle in these places. According to the source of its water supply, the vegetation of arid regions may be divided into two general groups, xerophytes and phreatophytes. Xerophytes are the larger group.

ROBINSON, T. W. 79

1957. The phreatophyte problem. *In* Symposium on Phreatophytes, Pac. Southwest Reg. Meet., Amer. Geophys. Union, Sacramento, Calif., Feb. 14–15, 1957. Phreatophyte Subcomm., Pac. Southwest Inter-Agency Comm. p. 1–11. Processed.

This review of the phreatophyte problem lists specific research needs.

ROBINSON, T. W. 80

1958. Phreatophytes. U. S. Geol. Surv. Water-Supply Pap. 1423, 84 p., illus.

In the arid and semiarid regions of the Western United States, phreatophytes with their low economic value and high rate of consumptive use of water, pose a serious problem. It is estimated that phreatophytes (excluding such beneficial species as alfalfa) cover about 16 million acres in the 17 Western States and discharge as much as 25 million acre-feet of water into the atmosphere annually. Although little has been done so far to prevent this waste, much of the water undoubtedly can be salvaged by converting consumptive waste to consumptive use. There are two basic methods: Reducing consumptive waste by diverting water from the plants to other uses and increasing the efficiency of water use by substituting beneficial for nonbeneficial plant species. These methods, to be successful, require an understanding of the factors that affect the occurrence and amount of water used by phreatophytes and of climate, depth to and quality of ground water, and soil.

More than 70 plant species have been classified as phreatophytes; this report lists information concerning them. The available information about the phreatophytic characteristics of most of the species is meager, but for eight (pickleweed, rabbitbrush, saltgrass, alfalfa, cottonwood, willow, greasewood, and saltcedar) there are sufficient data to warrant separate discussions. The annual use of water by phreatophytes ranges from a few tenths of an acre-foot per acre to more than 7 acre-feet per acre.

In the Southwest, saltcedar, an exotic plant that develops a junglelike growth, has invaded and choked the normal overflow channels of streams so as to produce a flood hazard that must be reckoned with. In addition, the ponding effect of the dense growth results in above-normal sediment deposition in the area of growth and reduced deposition downstream, as was observed at the McMillan Reservoir on the Pecos River in New Mexico.—From auth. abstr.

ROBINSON, THOMAS W. 81

1959. Phreatophyte research in Western United States, October 1958 to March 1959. U. S. Geol. Surv. Circ. 413, 14 p.

This report states that there are three categories of active research projects on phreatophytes in the Western States: Hydrologic and ecologic, eradication and control, and salvage. It covers only projects that were currently in progress or for which plans were firmly developed during the period October 1958 to March 1959.

ROBINSON, T. W. 82

1961. Definition, major species, areal extent of infestation, consumptive waste of water, potential salvage. *In* Pacific Southwest Inter-Agency Committee Minutes of the 61–4 Meeting. Las Vegas, Nev., Nov. 29, 1961. p. 6–20, illus. Processed.

This paper summarizes knowledge about phreatophytes, including knowledge about water losses by species. The increase of the areal extent of saltcedar is stressed. As of 1961 it was estimated that there were 885,000 acres of this species in the Western United States. The Pecos Basin is an example of places where it has spread rapidly. Prior to 1912 no tamarisks were recorded there, but by 1960 there were 50,000 acres of them.

ROBINSON, T. W. 83

1964. Phreatophyte research in the Western States, March 1959 to July 1964. U. S. Geol. Surv. Circ. 495, 31 p.

Between March 1959 and July 1964, 48 research projects on phreatophytes were reported as active in the arid and semi-arid regions of the Western United States. This circular is a revision of U. S. Geol. Surv. Cir. 413 (Robinson 1959, 81).

ROBINSON, T. W. 84

1968. The effect of desert vegetation on the water supply of arid regions. *In* Water for Peace: International Conference on Water for Peace—May 23–31, 1967. U.S. Govt. Print. Off. v. 3: 622–633, illus.

Xerophytes and phreatophytes are compared in this report, and some phreatophytes and their uses are listed. The typical water requirements of various phreatophytes are listed and the resultant draft on the ground water is discussed.

THOMAS, HAROLD E. 85

1963. Causes of depletion of the Pecos River in New Mexico. U. S. Geol. Surv. Water-Supply Pap. 1619–G, 44 p., illus.

The contribution of water to the Pecos River in the reach between Alamogordo Dam and Red Bluff Reservoir [N. Mex.] has been trending downward for the past 40 years. This reach, the middle basin of the Pecos River, has been the scene of several significant changes in recent decades, each of them capable of causing a depletion of the Pecos River flow. Although several other factors may be involved in the streamflow depletion measured to date (1958), the principal causes are conceded to be the ground-water developments near Roswell and near Carlsbad, the natural factors of drought, and encroaching phreatophytes.—Auth. abstr.

THOMPSON, C. B. 86

1958. Importance of phreatophytes in water supply. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 84 (IR 1): 1–17, illus.

This paper reports on the spread and increase in growth of phreatophytes, primarily saltcedar, in the Western United States, particularly in New Mexico, and the effect on water supply.

TROXELL, HAROLD C. 87

1933. Ground water supply and natural losses in the valley of the Santa Ana River between the Riverside Narrows and the Orange County line. *In* Water Losses under Natural Conditions from Wet Areas of Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 141–172, illus.

A record of noneconomic loss of water along the Santa Ana River, Calif., from the Riverside Narrows to the Orange County line, together with an estimate of inflow from ground water above Lower Santa Ana Canyon, is presented. The losses amounted to 17,500 acre-feet in 1930–31 and 16,300 acre-

feet in 1931–32. The writer concludes that the water, which under natural conditions is consumed by uneconomic plant life, could in large part be recovered by pumping from wells, so that the water table would be drawn down below the root zone. The installation of pumps in this area would make available the large underground reservoir that lies unused.

TURNER, S. F., AND SKIBITZKE, H. E. 88

1952. Use of water by phreatophytes in 2,000-foot channel between Granite Reef and Gillespie Dams, Maricopa County, Arizona. Amer. Geophys. Union Trans. 33(1): 66–72, illus.

This paper summarizes data obtained in a study of transpiration by phreatophytes in the channels of the Salt and Gila Rivers, between Granite Reef and Gillespie dams, Maricopa County, Ariz. The study was made in the spring of 1950 by the U. S. Geological Survey in cooperation with the Corps of Engineers, United States Army. The kind and amount of phreatophytic growth was mapped in the area covered by a proposed flood-control channel, 2,000 feet wide, extending between the two dams. Most of the mapping was done from the air; recent aerial photographs were used. Transpiration by the phreatophytes was computed through use of the results of the mapping combined with water-use factors developed by experimental work done by the Geological Survey in Safford Valley, Ariz., during 1943 and 1944.

Estimates of future phreatophyte use of water and of the amount of water that might be saved by clearing and maintaining the channel area were based on extensions of water-level graphs to include the next 50 years and on the experimental work at Safford. The calculations were as follows: (1) Total estimated transpiration from ground water at the time of the investigation, 29,000 acre-feet per year; (2) estimated average transpiration from ground water, within the channel area, during the period 1950–99 (*a*) without Colorado River water, 22,200 acre-feet per year and (*b*) with Colorado River water in 1960, 29,900 acre-feet per year; (3) estimated average water saving effected by channel clearing, 1950–99 (*a*) without Colorado River water, 16,600 acre-feet per year and (*b*) with Colorado River water in 1960, 22,400 acre-feet per year.—From auth. abstr.

U. S. SENATE 89

1963. Phreatophyte control in the Pecos River Basin. Hearing before the Subcomm. on Irrig. and Reclam. of the Comm. on Interior and Insular Aff., May 21, 1963, U. S. Congr. 88th, 1st Sess. 48 p., illus.

This publication reports on the subcommittee hearing on Senate Joint Resolution 49 authorizing a water salvage program in the Pecos River Basin in New Mexico and Texas. Estimates of gain in consumptive use of water and of the economic value of the gain are stated.

WOODS, L. G. 90

1966. Multiple use management of mountain riparian vegetation. *In* Vegetation Management on Flood Plains and Riparian Lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66–3 Meet., Albuquerque, N. Mex., Aug. 30, 1966. p. 37–43. Processed.

The Forest Service has issued a special watershed management policy for the Southwest which recognizes the importance of management to improve water yield.

Streamside zones are usually the sensitive tension areas where conflicts in uses and competition for resources and uses are found. These are the areas where the district ranger must do a professional job of coordinated land management. These are also the areas where multiple use restraints limit what can or cannot be done with respect to manipulating vegetation. This does not necessarily preclude the possibilities of intensive management of streamside vegetation for increased water yield. It does impose on the water-

shed scientist a greater number of multiple use restraints which must be complied with to obtain multiple use objectives and the proper combination of uses of public lands which, by law, are to be managed for the greatest public good. An alert watershed scientist will select areas for intensive water management which are not burdened with excessive multiple use restraints.

Areas exist which have excessive riparian vegetation which can be thinned and intensively managed for water yield improvement.

Water users in the arid Southwest must recognize that multiple use management of mountain riparian vegetation in the Southwest will require careful surveys, analyses, and studies to set forth the prescriptions for intensive management for increased water yield.

Watershed scientists, in planning for increasing water from National Forest watersheds in the Southwest, will be confronted with many multiple use restraints which will require careful coordinated planning to develop feasible projects that will command public support.—From auth. sum.

See also 39, 47, 51, 149, 332, 356, 364.

DIRECT MEASUREMENT OF WATER LOSSES

EARLY STUDIES ON TRANSPIRATION AND EVAPOTRANSPIRATION RATES

ABBE, CLEVELAND 91

1905. A first report on the relation between climate and crops. U.S. Weather Bur. Bull. 36, 386 p.

A thorough review of studies on plant-water relations. The effect of sunshine and heat in stimulating transpiration was studied in England as early as 1691.

ANDERS, J. M. 92

1878. On the transpiration of plants. Amer. Nat. 12(3): 160–171.

Early studies of plants grown in pots demonstrated relationships of light and temperature to losses of water from various plants.

BAKKE, A. L. 93

1914. Studies on the transpiring power of plants as indicated by the method of standardized hygrometric paper. J. Ecol. [London] 2(3): 145–173.

Elaborate experimentation using cobalt paper was reported in these early studies of water losses from plants.

BATES, CARLOS G. 94

1923. Physiological requirements of Rocky Mountain trees. J. Agr. Res. 24(2): 97–164, illus.

Although primarily directed toward forestry management, this report presents material relating to evapotranspiration in the forests of Wyoming and Colorado during the years 1917–20. Information was collected on transpiration, wilting coefficients, sap densities, and the absorption of water from trees growing in pots, under both natural and greenhouse conditions.

BERGEN, JOSEPH Y. 95

1904. Transpiration of sun leaves and shade leaves of *Olea europaea* and other broad-leaved evergreens. Bot. Gaz. 38(4): 285–296.

Experiments were made near Naples, Italy, to determine the relative amount of transpiration by sun leaves and shade leaves of several species. The trees and shrubs studied were: *Olea europaea* var. *sativa, Pistacia lentiscus, Quercus ilex,* and *Rhamnus alaternus.*

BERGEN, JOSEPH Y. 96

1904. Relative transpiration of old and new leaves of *Myrtus* type. Bot. Gaz. 38(6): 446–451.

BLAYDES, GLENN W. 97

1928. A survey of rates of water loss from leaves. Ohio J. Sci. 28(2): 99–118.

For 1 year beginning in the fall of 1925, water losses from 123 species were measured; cobalt-chloride paper was used in making the measurements. The results obtained were entirely qualitative but showed interesting relationships of the measurements to species, age of leaf, time of day, and other factors.

BLAYDES, GLENN W. 98

1935. Water-vapor loss from plants growing in various habitats. Ohio J. Sci. 35(2): 112–130.

Determinations were made of the standard water-vapor loss ratio for 148 species of plants, representative of 16 plant associations located in the deciduous forest formation of Ohio and Indiana, which includes some riparian and swamp environments. The method, involving use of cobalt-chloride paper, was chosen because of its ease of application in the field.

The investigation indicated that the standard water-vapor loss is not necessarily correlated with the position of a species in a relative scale of xerophytism, as indicated by the usual habitat of that species. Many xerophytic species exhibit relatively high rates of water loss, and many mesophytic species have low rates.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 99

1913. The water requirements of plants. I. Investigations in the Great Plains in 1910 and 1911. U.S. Dep. Agr. Bur. Plant. Ind. Bull. 284, 49 p., illus.

This paper gives a full description of transpiration studies up to and including some started at Akron, Colo., in 1910.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 100

1913. The water requirements of plants. II. Review of the literature. U.S. Dep. Agr. Bur. Plant Ind. Bull. 285, 96 p.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 101

1914. Relative water requirements of plants. J. Agr. Res. 3(1): 1–64, illus.

Studies were made at Akron, Colo., from 1911 to 1913 on about 50 species and varieties of crops and weeds, to determine their water requirements (ratio of weight of water absorbed to the weight of the dry matter produced). Plants were grown in large galvanized iron pots, which were tightly covered to prevent loss of moisture by evaporation.

The weather factors measured included solar radiation, wet-bulb depression (differential thermograph), air temperature (air thermograph), and wind velocity (anemometer). Evaporation was measured by means of two water-filled tanks. Transpiration and evaporation were found to be closely correlated with air temperature, solar radiation, and wet-bulb depression readings.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 102

1916. Hourly transpiration rate on clear days as determined by cyclic environmental factors. J. Agr. Res. 5(14): 583–650, illus.

This paper deals with measurements of transpiration on clear days at Akron, Colo., in relation to environmental factors.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 103

1916. Daily transpiration during the normal growth period and its correlation with the weather. J. Agr. Res. 7(4): 155–212, illus.

Data obtained in this classic study on the daily transpiration of a large number of crops and the extent to which transpiration is correlated with various weather factors are completely summarized.

BRIGGS, LYMAN J., AND SHANTZ, H. L. 104

1917. Comparison of the hourly evaporation rate of atmometers and free water surfaces with the transpiration rate of *Medicago sativa*. J. Agr. Res. 9(9): 277–292, illus.

Evaporation from a shallow black pan is correlated more closely with actual transpiration than that from any of the other devices tested. Evaporation rates as measured by a shallow and a deep evaporation pan and by four types of atmometers (white cylinders, brown cylinders, white spheres, and white Bellani plates) were compared with water losses from alfalfa (*Medicago sativa* L.), measured by automatic scales. The tests and readings were made in Akron, Colo., in July 1916.

CLAPP, G. L. 105

1908. A quantitative study of transpiration. Bot. Gaz. 45(4): 254–267.

The autographic Ganong transpirometer was used to determine water loss from plants. The purpose of the study was to determine which plants are best suited for use in transpiration studies and, therefore, should transpire relatively large amounts of water and be easily obtainable.

COPELAND, EDWIN BINGHAM 106

1902. The rise of the transpiration stream: an historical and critical discussion. Bot. Gaz. 34 (3 and 4): 161–193, 260–283.

FORTIER, SAMUEL 107

1907. Evaporation losses in irrigation and water requirements of crops. U.S. Dep. Agr. Exp. Sta. Bull. 177, 64 p., illus.

This publication reports many studies in evaporation and discusses research which was started in 1903 by the U. S. Department of Agriculture in cooperation with the University of California. The studies used the weighing method in determining water losses from plants growing in tanks.

GANONG, W. F. 108

1904. New precision-appliances for use in plant physiology. II. Bot. Gaz. 37(2): 145–152, illus.

This paper describes an autographic transpirometer which records changes in plant weight on a chart fastened to a revolving drum.

HORTON, ROBERT E. 109

1923. Transpiration by forest trees. Mon. Weather Rev. 51(11): 571–581, illus.

Results published by von Höhnel (1879, 131) were evaluated to determine the amount of water transpired by forest trees. The author of this report also conducted his own experiments, using similar but more elaborate methods and more test trees. The growth patterns of each species were established and compared with the von Höhnel results. From growth measurements and transpiration ratios, estimates were made of water use by fully grown trees.

KIESSELBACH, T. A. 110

1915. Transpiration as a factor in crop production. Nebr. Agr. Exp. Sta. Res. Bull. 6, 214 p., illus.

This bulletin presents an exhaustive treatment of water losses, summarizing past research and elaborate studies in Nebraska.

KITTREDGE, JOSEPH, JR. 111

1937. Natural vegetation as a factor in the losses and yields of water. J. Forest. 35(11): 1011–1015.

KNIGHT, R. C. 112

1922. Further observations on the transpiration, stomata, leaf-water-contents, and wilting of plants. Ann. Bot. [London] 36: 361–383, illus.

LEATHER, J. WALTER 113

1910 and 1911. Water requirements of crops in India. Mem. Dep. Agr. India, Chem. Ser. [Calcutta, India] Part I, 1(8): 133–184, Part II, 1(10): 204–281.

Data on plants grown in pots were used in estimating field water requirements of Indian crops.

LEE, CHARLES H. 114

1912. An intensive study of the water resources of a part of Owens Valley, California. U.S. Geol. Surv. Water-Supply Pap. 294, 135 p., illus.

One of the earliest water resources studies was carried on in Owens Valley, Calif., where tanks of saltgrass were used. Evapotranspiration losses varied greatly, depending on depth to water table.

LIVINGSTON, BURTON EDWARD 115

1908. A method of controlling plant moisture. Plant World 11(2): 39–40.

This article describes a procedure developed for maintaining constant moisture conditions in the soil of pots, boxes, or other containers in which plants are grown. The method utilizes a porous clay cup, stoppered with a perforated rubber stopper bearing a tube of glass and rubber or lead connected to a reservoir. The cup is buried in the soil of the container. Following placement of the cup, the plants or seeds are placed in the container. The soil draws moisture from the cup, which is kept filled by the reservoir. Water control and pressure may be instituted by elevating or lowering the reservoir. It is easily possible to service several pots from one reservoir.

LIVINGSTON, BURTON EDWARD 116

1913. The resistance offered by leaves to transpirational water loss. Plant World 16(1): 1–35, illus.

Cobalt paper and porous-cup atmometers were used to furnish data on water losses from plants.

LIVINGSTON, BURTON EDWARD, AND BROWN, WILLIAM HENRY 117

1912. Relation of the daily march of transpiration to variations in the water content of foliage leaves. Bot. Gaz. 53(4): 309–330.

LIVINGSTON, BURTON E., AND SHREVE, EDITH B. 118

1916. Improvements in the method for determining the transpiring power of plant surfaces by hygrometric paper. Plant World 19(10): 287–309.

LLOYD, FRANCIS E. 119

1912. The relation of transpiration and stomatal movements to the water-content of the leaves in *Fouquieria splendens*. Plant World 15(1): 1–14.

Comparative volumetric and gravimetric data show that, in the ocotillo, the ratio between the intake and outgo of water is not a constant but that the outgo during the day is greater than the intake. The reverse relation obtains during the night.

The decrease of water in the leaf occurs during the opening of the sto-

mata. These organs are, therefore, not closely regulatory of the loss of water from the leaf and are ineffectual in maintaining a constant supply of leaf-water. Transpiration is, therefore, at times too great, and the stomata do not serve to reduce it by closing movements; they may, however, limit it in a purely passive manner.—From auth. conclusion.

MEYER, BERNARD S. 120

1927. The measurement of the rate of water-vapor loss from leaves under standard conditions. Amer. J. Bot. 14(10): 582–591.

This paper reports a quantitative method for measuring, by means of cobalt-chloride paper, the rate of water-vapor loss from leaves of eight various plants under a standard set of conditions.

SHANTZ, H. L., AND PIEMEISEL, L. N. 121

1927. The water requirements of plants at Akron, Colo. J. Agr. Res. 34(12): 1093–1190, illus.

Results of the entire study period (1911–17) at Akron, Colo., are fully summarized; transpiration ratios (weight of water absorbed to weight of dry matter produced) were used.

SHAPIRO, A. A., AND DE FOREST, H. 122

1932. A comparison of transpiration rates in chaparral. Ecology 13(3): 290–295.

Of eight southern California chaparral species tested by means of their relative transpiration indices, *Rhus integrifolia* and *R. laurina* are indicated as highly conservative users of soil water. White sage, *Salvia apiana,* whose leaves bear a covering of hairs, appears to be the most lavish user of water. Cobalt chloride paper was used.—From auth. sum.

SHREVE, EDITH B. 123

1923. Seasonal changes in the water relations of desert plants. Ecology 4(3): 266–292.

To discover the responses by which typical desert plants meet conditions that approach the critical point, the daily march of transpiration was investigated for a perennial, a spring annual, and a summer annual during seasons in which they thrive in southern Arizona. For comparison, the same experiments were performed on a cultivated plant which will thrive during certain unfavorable seasons. The plants involved were *Encelia* sp., *Streptanthus* sp., and *Amaranthus* sp.

The three native species showed an ability to increase their resistance to water loss with increasing aridity. The cultivated plant did not show this phenomenon, but the system was destroyed, since the plant died under the more arid conditions.

SHREVE, EDITH B. 124

1924. Factors governing seasonal changes in transpiration of *Encelia farinosa.* Bot. Gaz. 77(4): 432–439.

Studies were made of factors reducing relative transpiration in the desert perennial, *Encelia farinosa.*

SPALDING, V. M. 125

1904. Biological relations of certain desert shrubs. I. The creosote bush (*Covillea tridentata*) in its relation to water supply. Bot. Gaz. 38(2): 122–138.

This was a progress report of work being done on transpiration from the creosote bush at the Desert Laboratory of the Carnegie Institute, Tucson, Ariz.

SPALDING, V. M. 126

1905. Soil water in relation to transpiration. Torreya 5(2): 25–27.

This report relates the amount of soil water to the rate of transpiration.

Seedlings of the creosote bush and palo verde were grown in cans. To determine the rate of transpiration, the cans were covered with bell jars and a hygrometer was used to take readings on the amount of water transpired. In experiments with both plants, one set would receive water while the other would receive less water or no water at all. Observations made before and after the addition of water showed that the transpiration rate after watering had increased as much as three times the rate before water was added.

STAHL, ERNST 127

1894. Einige Versuche über Transpiration und Assimilation. Bot. Zeitg. [Leipzig] 52: 117–146. [In German]

Use of cobaltpaper in determining transpiration rates is based on the principle that cobalt chloride appears blue when dry and red when moistened.

THOMAS, NESTA, AND FERGUSON, ALLEN 128

1917. On the reduction of transpiration observations. Ann. Bot. [London] 31(122): 241–255.

The results of extensive experimentation in England indicate that the figures usually given to show the relation between the evaporation from a transpiring leaf surface and a circular water surface of the same area are subject to serious errors.—From auth. sum.

TRANSEAU, EDGAR N. 129

1911. Apparatus for the study of comparative transpiration. Bot. Gaz. 52(1): 54–60, illus.

This study includes data collected by synchronous exposure of several plants to a variety of conditions of light, temperature, and humidity. Ratios between transpiration and evaporation rates were determined. Automatic weighing and recording of evaporation rates were done by a modified Ganong transpirograph, consisting of a hygrothermograph, chronograph, chemical balance, weight droppers, and irrigators.

VEIHMEYER, FRANK J. 130

1927. Some factors affecting the irrigation requirements of deciduous orchards. Hilgardia 2(6): 125–284, illus.

VON HÖHNEL, FRANZ R. 131

1879. Über die Wasserverbrauchsmengen unserer Forstbäume Beziehung auf die forstlich-meteorologischen Verhältnisse. (Water requirements of forest in relation to forest meteorological conditions.) Forsch. Geb. Agr.-Phys. [Heidelberg] 2: 398–421 [In German].

Compiler's Note.—Extensive experiments with tree seedlings planted in pots were carried out for many species and varieties of trees. The quantity of water transpired was obtained from daily weighings and related weight of dry-leaf substance. From these figures estimates of water loss from forests were developed (Zon 1912, 55).

WEAVER, J. E., AND CRIST, JOHN W. 132

1924. Direct measurement of water losses from vegetation without disturbing the normal structure of the soil. Ecology 5(2): 153–170, illus.

A method has been devised for determining the water losses from square-foot areas of native grassland and cultivated crops without disturbing the soil structure. It consists of excavating soil columns a square foot in cross-sectional area and 3 feet deep and forcing galvanized iron cylinders over these tightly as they are formed. The columns are then smoothly cut off, and bottoms are sealed to the cylinders, which, after weighing, are replaced in trenches of appropriate width and depth so that, after the interspaces between the cylinders in a trench are refilled, the vegetation in the containers

is completely surrounded by undisturbed grassland or a crop similar to that enclosed in the soil column. The containers are covered during rain, and water is added to the soil as needed for a 15-day period, after which they are reweighed and the losses calculated. Direct losses from the soil and from soil covered with dead plants are determined by control soil columns.—From auth. sum.

WEAVER, J. E., AND MORGENSEN, A. 133
1919. Relative transpiration of coniferous and broad-leaved trees in autumn and winter. Bot. Gaz. 68(6): 393–424, illus.

See also 55, 603.

LYSIMETERS, TANKS, EVAPOTRANSPIROMETERS, AND SIMILAR EQUIPMENT

General Discussions of the Lysimetric Approach

HARROLD, L. L. 134
1966. Measuring evapotranspiration by lysimetry. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 28–33.

This paper presents a full literature review of lysimetry and includes a description of the uses and advantages of the various types. Evapotranspiration can be measured accurately by lysimeters and reliable data obtained if they are designed, installed, situated, and operated so as to be representative of natural areas to which their results are to be applied.

HUDSON, J. P. 135
1965. Gauges for the study of evapotranspiration rates. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 443–451.

Evapotranspiration gauges of many different patterns have been evolved. Despite their drawbacks, such gauges have reached a stage where they can be used with reasonable reliability to measure evapotranspiration rates from the sample of soil and plants which they contain. Where gauges are to be used to estimate rates of water loss on a field scale, the main problem is to ensure that they represent a fair sample of their surroundings. Much of the earlier work contributed little to our understanding of evapotranspiration because exposure of plants and containers was so unnatural that results could not be extrapolated to a field scale, but trends toward increasing sizes of gauges or the use of relatively large numbers or both, coupled with more realistic exposures, should enable them to be used to give far better estimates of evapotranspiration from plants growing under natural conditions or crops growing in the field.—From auth. conclusions.

KOHNKE, HELMUT, DREIBELBIS, F. R., AND DAVIDSON, J. M. 136
1940. A survey and discussion of lysimeters and a bibliography on their construction and performance. U.S. Dep. Agr. Misc. Pub. 372, 68 p., illus.

Lysimeters have distinct limitations, but many questions concerning pedology, soil fertility, and hydrology can be answered by the correct use of lysimeters. Filled-in lysimeters may fulfill useful tasks in fertility investigations if a sound water balance is maintained in the soil, but for pedologic and hydrologic studies, carefully designed monolith lysimeters seem to be indispensable.—From auth. conclusion.

MAKKINK, G. F. 137

1959. Lysimeters in the Netherlands. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 5–12.

The aims, construction, vegetation, instrumental arrangements, and research possibilities of lysimeters in the Netherlands are discussed. In 1949, to make the most profitable use of the lysimeter installations and observations, the Committee for Hydrological Research in the Netherlands initiated a working party on lysimeters.

A few examples are given of calculations applying the results of work with lysimeters to natural and agricultural vegetation elsewhere in the country and of checks on these calculations.

A bibliography on Dutch lysimeter research concludes the paper.

MAKKINK, G. F. 138

1959. Limitations and perspectives of lysimeter research. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 13–25.

The use of lysimeters is likely to yield results that do not fully represent what occurs in nature. The vegetation in the lysimeter may not be similar to the cover surrounding it. The soil in the lysimeter may not fully represent the soil with which it is compared. The moisture relationships in the lysimeter may be different from those in the surrounding area, especially if the lysimeter was filled with soil after construction rather than being of the monolith type.

This paper discusses limitations in the use of lysimeters, suggests some ways of minimizing the limitations, considers an analytical, schematic approach to computing evapotranspiration for short periods of time, and discusses extrapolation of lysimeter data.

PELTON, W. L. 139

1961. The use of lysimetric methods to measure evapotranspiration. *In* Symposium on Evaporation, Toronto, Canada, 1961. Canada Dep. N. Aff. and Nat. Resour., Water Resour. Br., Hydrol. Symp. Proc. [Ottawa] 2: 106–134.

A brief history of the development of lysimetry over nearly 300 years is given and the design of weighing-type lysimeters which can be used to study evapotranspiration is shown. The value of lysimeters as tools for evapotranspiration research is assessed.—From auth. synop.

VAN BAVEL, C. H. M. 140

1961. Lysimetric measurements of evapotranspiration rates in the eastern United States. Soil Sci. Soc. Amer. Proc. 25(2): 138–141.

A review is presented of various methods to determine the evapotranspiration rates under field conditions. It is shown that the data which have been collected by a suitable lysimetric method are the only ones that exist in quantity and can be considered reliable.

The conditions which must be met by a lysimeter installation for the accurate and representative measurement of the evapotranspiration rate are reviewed. It is shown that both the exposure and the moisture conditions in the soil of the lysimeter must be representative of those in the surrounding area if realistic values are to be obtained.

Selected data from four locations in the Eastern United States [Coshocton, Ohio; Seabrook, N. J.; Waynesville, N. C.; and Raleigh, N. C.] are presented and compared. It is shown that data for grass cover under a variety of geographic and climatological conditions do not vary greatly from one

another. Such dependable comparisons as are available between different crops show that the differences between corn, wheat, and meadow crops are small, though not insignificant. The need for additional and adequate lysimetric measurements of evapotranspiration rates in the Eastern United States is discussed, as well as the necessity for making pertinent meteorological measurements to aid in the generalization of the data.—From auth. abstr.

See also 25, 29, 199, 677, 682.

Containers with Constant Water Table

Metal

BAY, ROGER R. 141

1966. Evaluation of an evapotranspirometer for peat bogs. Water Resour. Res. 2(3): 437–442, illus.

A bottomless evapotranspirometer, 10 feet in diameter, was developed for use in saturated organic soils and was tested under open bog conditions. Weekly water losses from two evapotranspirometers compared favorably with pan evaporation and with potential evapotranspiration calculated by climatological methods. Provided that they are constructed to reach slowly permeable peat types to minimize bottom seepage, these installations appear to be useful for measuring evapotranspiration to test the applicability of formulas based on climatological data or to measure on site the effects of water management.—Auth. abstr.

BLANEY, HARRY F., EWING, PAUL A., MORIN, KARL V., AND OTHERS 142

1942. Consumptive water use and requirements. *In* The Pecos River Joint Investigation. Reports of the Participating Agencies. Natl. Resour. Plann. Board. p. 170–230, illus.

The principal methods of determining consumptive water use in this study were tank experiments, soil-moisture studies, ground-water fluctuations, and for large areas, inflow-outflow and integration procedures.

The tank experiments included elements of new research, but the other approaches followed standard practices. An evapotranspiration station, with tanks placed in surroundings of natural growth of the same species, was established and maintained for 1 year (1940) at Carlsbad, N. Mex., to determine the consumptive water use for saltgrass, sacaton, tules, and saltcedar (tamarisk) and evaporation from bare soil and free-water surface.

The water table in the bare soil tank (1940 water loss, 31.87 inches) and saltgrass tank (water loss, 54.19 inches) was maintained at 2 feet below ground surface. The two sacaton tanks had 2- and 4-foot water tables, respectively, and a (1940) water loss of 48.10 and 41.37 inches.

The grass species were readily established in the tanks, but the saltcedar gave considerable difficulty and required replanting; consequently, normal growth was not attained until August. This means that the figures on consumptive use of water by saltcedar are based on only a 3 months' record for the two tanks. Yearly figures were calculated by the August-September-October ratio with sacaton and then applied to the missing months. Water loss for saltcedar was calculated as 61.74 inches (2-foot water table) and 52.76 inches (4-foot water table). Evaporation from a standard Weather Bureau pan was 92.64 inches.

An empirical formula for estimating water losses was developed by use of the relationship of temperature, evaporation, and measured consumptive use of water from tanks at Carlsbad. The consumptive use of water by vegetation growing along the various sections of the Pecos River was then computed by use of this formula.

BLANEY, HARRY F., AND YOUNG, A. A. 143

1930. Evaporation and transpiration losses from moist areas. *In* Rain-

fall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain. Calif. Dep. Public Works Div. Water Resour. Bull. 33: 105–162, illus.

The original purposes of this study were to determine, by tank experiments, the evaporation from bare, uncultivated, fine sandy loam soils and the consumptive use of water by saltgrass (*Distichlis spicata*) and bermudagrass (*Cynodon dactylon*), where the water table is 6 feet or less beneath the ground surface. The equipment was installed early in 1929 in San Bernardino and Orange Counties, Calif.

Additional tank experiments were conducted to determine the consumptive use of water by tules, cattails, rushes, and willows. Investigations were carried on to determine the effect of oil films in preventing evaporation from water surfaces, with a view to finding a means of preventing large evaporation losses from storage reservoirs. Preliminary data are given in this bulletin, but more complete results are published in a bulletin by Taylor and Nickle (1933, 148).

BONDE, A. N., IVES, J. D., AND LAWRENCE, D. B. 144

1961. Ecosystem studies at Cedar Creek natural history area. III: Water use studies. Minn. Acad. Sci. Proc. 29: 190–198.

Constant water-table lysimeters, 45 inches in diameter and 2 feet deep, were used in a study of the disposal of solar energy in Minnesota where the water table is close to the surface. Comparisons of water use were made between open water and sedge, marsh grass, willow, alder, and tamarack.

MCGINNIES, W. G., AND ARNOLD, JOSEPH F. 145

1939. Relative water requirements of Arizona range plants. Ariz. Agr. Exp. Sta. Tech. Bull. 80: 167–246, illus.

Water requirements of 28 species of Arizona range plants and five crop plants were determined under varying climatic conditions during the period 1931 to 1936. The experimental work was done at the Desert Grassland Station on the Santa Rita Experimental Range, located about 30 miles south of Tucson, Ariz.

The water requirement determinations for the crop plants were used in comparing climatic conditions at the Desert Grassland Station with those at Akron, Colo., and elsewhere in the Great Plains area. The native species included six groups of plants: (1) Perennial grasses of the desert grassland, (2) perennial grasses of plains grassland, (3) southern tall grasses, (4) winter annuals, (5) summer annuals, and (6) xerophytic trees and shrubs.

As a group, the perennial grasses were fairly uniform in their water requirement. There was less difference between geographical groups than there was within the groups. The summer annuals had lower water requirement values than the winter annuals. The winter annuals were at least as efficient in the use of water as the perennial grasses during the same season. The summer annuals, as a group, had lower water requirements than the perennial grasses. The trees and shrubs had much higher water requirements than any other group.—From auth. sum.

PARSHALL, R. L. 146

1937. Laboratory measurement of evapo-transpiration losses. J. Forest. 35(11): 1033–1040, illus.

The evapotranspiration losses of several common plants were investigated by growing them in soil tanks with shallow depths of soil and high water tables. The studies covered the growing seasons of 1929, 1930, 1931, and 1932 and were conducted under a cooperative agreement between the Bureau of Agricultural Engineering, U. S. Department of Agriculture, and the Colorado Agricultural Experiment Station at Fort Collins, Colo.

The results of the investigation are not conclusive as to the actual use of water by plants when growing in a natural environment. The results obtained were reasonably consistent but do not represent enough observations

on any one crop to establish definite relations. It is probable that the evapotranspiration loss under actual field conditions would be less than that reported.—From auth. introd. and sum.

SPEIR, WILLIAM H. 147

1962. Installation and operation of nonweighing lysimeters. Soil Crop Sci. Soc. Fla. Proc. 22: 167–176.

Twelve lysimeters of the constant-water-table type, 9½ feet long, 5 feet wide, and 5¼ feet deep, were built in 1950 in southeastern Florida. Water loss was determined by the amount of water added each day.

TAYLOR, COLIN A., AND NICKLE, HARRY G. 148

1933. Investigations in the Mojave River area. *In* Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 74–87, illus.

This study was designed to determine the consumptive use of water by tules (*Scirpus* sp.) and cattail (*Typha latifolia*) and to demonstrate the impracticability of attempting to determine their use of water in swamps from experiments conducted with tules planted in isolated tanks outside their natural environment.

The mean annual consumptive use of water by tules (*Scirpus olneyi*) growing in a tank located in a swamp, with natural conditions replicated, was found to be 84.5 inches depth per year. In contrast, the water loss from an exposed tank on the bank was 272.2 inches depth per year. For the same period the mean annual evaporation from a standard Weather Bureau pan located on a bank near the swamp was 82.5 inches.

TURNER, S. F., AND HALPENNY, L. C. 149

1941. Ground-water inventory in the upper Gila River Valley, New Mexico and Arizona: Scope of investigation and methods used. Amer. Geophys. Union Trans. 22(3): 738–744, illus.

An inventory of water resources of the upper Gila River is covered in this report. The inventory covered inflow-outflow measurements from several gauging stations, estimation of transpiration from cultivated crops and phreatophytes, and evaporation from water surfaces and moist soil. Of particular interest are the tank studies using tamarisk, baccharis (seepwillow), and bare soil.

The tanks were surrounded by bare soil, but the plants were very thin for most of the summer. By October, both tamarisk and baccharis measured only 3 to 4 feet in height; thus, results are not indicative of true water losses. For the period May 10 (date of installation) to Dec. 31, 1940, tamarisk with a 4-foot water level used 47.9 inches of water and with a 2-foot water level used 61.1 inches. Baccharis used 31.6 and 52.0 inches, respectively, when grown under the same conditions. Bare soil with a 2-foot water level evaporated 39.7 inches of water.

VENKATARAMAN, S. 150

1961. Evapotranspiration as an agronomic factor. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 147–153.

Two types of evaporimeters with constant water tables were described.

YOUNG, A. A. 151

1933. Investigations in the Santa Ana River Valley and Coastal Plain. *In* Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 26–73, illus.

This bulletin gives summaries and conclusions derived from extensive studies, which were described in full, with preliminary data, in an earlier bulletin published by the California Division of Water Resources (1930, 58).

Use of water in tanks planted to saltgrass (*Distichlis spicata*) and bermudagrass (*Cynodon dactylon*) was influenced by the availability of moisture in the soil and the depth to the water table. Grasses in tanks having the highest water tables used the most water. During the year ending April 30, 1932, saltgrass in tanks having water tables 1 foot below the surface used water at the rate of 42.75 acre-inches per acre; with a 2-foot depth, the rate was 36.23 acre-inches and with a 5-foot depth, 22.12 acre-inches. In general, the ratio of the use of water to depth of water table was about the same for bermudagrass as for saltgrass.

Willow (*Salix laevigata*) used more water than either of the two wild grasses with which tests were made. A fully exposed single clump of willow used 52.71 acre-inches per acre with a water table at a depth of 2 feet during an 11-month period. This was 83.5 percent of the evaporation from a standard Weather Bureau pan.

Wire rush (*Juncus balticus*) grows in a limited area in the Santa Ana Valley, Calif., where the ground-water level is high. Its consumptive use of water, measured from a 2-foot water table, is high, exceeding that of grasses or willow.

Consumptive use of water by tules (*Scirpus* sp.) and cattail (*Typha latifolia*) as determined by measurements in tanks in exposed locations was not considered indicative of the actual use by these plants growing in their natural environment; under the experimental conditions there was greater solar radiation, lower humidity, and greater wind movement than are to be found under natural swamp conditions. Instances were noted of tules in tanks using an acre-inch or more of water per 24 hours at the Santa Ana station, and an extreme use of 3.6 acre-inches per acre per 24 hours at Prado was noted.—From auth. sum.

See also 137, 138, 251, 364, 365, 366, 449, 536.

Large, Plastic-lined Pits

DYLLA, A. S., AND MUCKEL, DEAN C. 152

1964. Evapotranspiration studies on native meadow grasses. Humboldt Basin, Winnemucca, Nevada. Univ. Nev., Max C. Fleischmann Coll. Agr. and U. S. Dep. Agr., Agr. Res. Serv. Reno Nev. R9, 29 p., illus.

Three years (1961, 1962, and 1963) of measurements of evapotranspiration by native meadow grasses grown in lysimeters at the Winnemucca (Nev.) Experimental Station are presented. A discussion is included on the installation and operation of the lysimeters, also called evapotranspiration tanks. Hay yields were studied to compare effects of varied water content in the soil on production.—From auth. sum.

DYLLA, A. S., AND TOVEY, RHYS 153

1962. Plastic membrane tanks for evapotranspiration determinations. Agr. Eng. 43(10): 584–585, illus.

Plastic membrane tanks used in Nevada to obtain evapotranspiration values for native vegetation are described. Most of the tanks were 10 feet square and 7.5 feet deep. A black polyvinyl plastic was used to line the bottom and sides of the pits dug in the ground. A 10-inch layer of gravel was distributed equally above and below a perforated plastic pipe system in the bottom in order to manage water-table levels efficiently. Soil was then backfilled. A float-valve system was used to regulate the water-table level. A water-balance input and output equation provides a means of evaluating evapotranspiration.

HUGHES, G. H., AND MCDONALD, C. C. 154

1966. Determination of water use by phreatophytes and hydrophytes. Amer. Soc. Civil Eng. Proc., J. Hydraul. Div. 92(HY 2): 63–81, illus.

Evapotranspiration from arrowweed, saltbush, and cattail and evaporation from bare soil with depths of 2 to 4 feet of water were measured in evaporimeters of 100 to 1,000 square feet in area along the lower Colorado River. Preliminary results show uses of 5.0 to 9.0 feet of water per year for arrowweed, 2.5 to 4.0 feet per year for saltbush, approximately 8.5 feet per year for cattail, and 0.3 to 0.9 foot per year for bare soil. Related meteorological data are included.—From. auth. abstr.

MCDONALD, CHARLES C., AND HUGHES, GILBERT H. 155

1968. Studies of consumptive use of water by phreatophytes and hydrophytes near Yuma, Arizona. U. S. Geol. Surv. Prof. Pap. 486-F, 24 p., illus.

Studies of transpiration by several species of flood-plain vegetation and evaporation from water surfaces and bare soil were carried out near Yuma, Ariz., during the 6-year period 1961–66. Arrowweed (*Pluchea sericea*), fourwing saltbush (*Atriplex canescens*), quailbrush (*Atriplex lentiformis*), and bermudagrass (*Cynodon dactylon*) were grown under controlled conditions in large tanks, about 1,000 square feet in area, and cattail (*Typha latifolia*) was grown in tanks 100 square feet in area. Excavated pits were filled with soil after being lined with plastic membranes. Water was fed into the bottom of the tanks to maintain a constant water table (varying from 2.0 to 5.5 feet below the surface), simulating that of the natural area. As water levels were dropped by evapotranspiration, automatic meters kept the water level at the desired depth. The larger tanks were also used for studies of evaporation from bare soil. Evaporation from water surfaces was measured by two standard U. S. Weather Bureau class *A* pans and by a ground-level tank, which was 10 feet by 10 feet in area. Related meteorological observations were made near the sites of the experiments, and those of nearby meteorological stations at Yuma Proving Ground and Yuma, Ariz., were used.

Annual consumptive use of water by the several species increased with the volume of vegetation, but the consumptive use per unit volume decreased as the plants approached maturity. Depth to the water table strongly influenced evaporation from bare soil; for water-table depths of 2.0 to 4.0 feet, evaporation varied from 3 to 20 inches yearly. Water-table depths moderately influenced transpiration by the two species of *Atriplex* (average yearly water use, 38 to 44 inches), although the depth of the tanks did not permit the water table to be held at sufficient depth to create substantial moisture stress. The cattail lysimeters utilized a total of approximately 100 inches of water, or about 8.5 feet, per year. Arrowweed, with the water table at 5.5 feet, used 96 inches per year. Bermudagrass, with the water table at 3.5 feet, used 73 inches per year.

MADLER, ROBERT R. 156

1966. Use of Bernardo lysimeter tank data to evaluate evapotranspiration of saltcedar by the energy balance method. Water Resour. and Util. Sect., U.S. Bur. Reclam., Albuquerque, N. Mex. 14 p., illus. Processed.

Six Bernardo lysimeters were installed during 1961, and planting of saltcedar shrubs was completed in March 1962. The water table for one pair of tanks was held at a constant depth of 3 feet, for another pair at 5 feet, and for a third pair at a variable depth conforming to the water table surrounding the Bernardo site.

Generally the vegetative density of saltcedar increased more in the lysimeter tanks having the greatest depth to the water table. Thus, plants

growing with the water table at 3 feet were slower to develop. Growth rate was faster in the tanks having constant depth to the water table. An increase in the vegetative density of saltcedar resulted in a corresponding 1.7 times increase in the ratio of measured to potential evapotranspiration. The seasonal values (May through September) of this ratio generally decreased in the tanks having a constant water table. This seasonal decrease is probably due to the maturing saltcedar growth and a reduction in vigorously growing shoots.

During the fourth growing season (1965), the tanks with a constant 3-foot water table showed not only significantly lower evapotranspiration ratios but also slower vegetative growth than the other tanks. This would indicate that salts were increasing in spite of yearly leaching and reducing both growth rate and relative water losses.

Rapid lowering of the water table reduced the availability of water to the saltcedar root systems, causing a temporary dormant period with decreased water loss and slower growth rate until the root system enlarged to reach available water.

The average annual water loss for two tanks with a constant water-table depth of 3 feet was 31.8 inches; for the two tanks with a 5-foot water table, it was 41.3 inches. The tanks with variable depth averaged 28.9 inches.

These lysimeter data on the relationship of measured evapotranspiration to vegetative density in saltcedar do not support the method of adjustment of evapotranspiration to a 100-percent volume density base for varying degrees of vegetative density used in a previous study in Safford Valley, Ariz. (Gatewood, Robinson, Colby, and others. 1950, 364)

ROBINSON, T. W. 157

1970. Evapotranspiration by woody phreatophytes in the Humboldt River Valley, near Winnemucca, Nevada. U. S. Geol. Surv. Prof. Pap. 491-D, 41 p., illus.

This report presents the results of cooperative studies of evapotranspiration by phreatophytes in the Winnemucca reach of the Humboldt River Valley. Water that is wasted by evapotranspiration from areas of low beneficial phreatophytes is one of the largest unknowns in the water budget of the reach. In order to obtain information with which to evaluate the consumptive waste, studies of the water use of four woody phreatophytes—greasewood, rabbitbrush, willow, and wildrose—were undertaken in evapotranspiration tanks at the Winnemucca test site.

Twelve tanks ranging in size from 30 feet square and 10.5 feet deep to 10 feet square and 7 feet deep were constructed. Seedlings of greasewood were planted in two tanks and of rabbitbrush in three tanks; cuttings of willow were planted in three tanks and of wildrose in three tanks. The 12th tank was left bare. The tanks were constructed in place by lining excavated pits with watertight plastic membranes, providing a water-distribution system on the bottom, and backfilling with the excavated material. The tanks were operated during the growing season April 1 to October 20 from 1961 to 1967, inclusive.

Evapotranspiration, expressed on an areal basis as depth over a unit area, gives no indication of growth conditions for which the information was obtained and may result in serious error when transposed to areas of dissimilar growth conditions. Some of the difficulties and uncertainties of the areal method may be avoided by expressing evapotranspiration on a volume-of-foliage basis, as a quantity of water per unit of foliage volume. The method presumes that transpiration by a species is proportional to the total transpiring leaf area and, so, proportional to the foliage volume. In the results of the studies, evapotranspiration is expressed in both quantities. The annual use of water ranged rather widely over the study period as the plants responded to the effect of plant damage, boron toxicity, depth to the water level, and warmth and length of the growing seasons.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 158

1963. Growth, development, and water use by saltcedar (*Tamarix pentandra*) under different conditions of weather and access to water. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 75–86, illus.

Near Buckeye, Ariz., six evapotranspirometers were installed in 1959 and planted to saltcedar in a cooperative endeavor by the U. S. Bureau of Reclamation and the U. S. Geological Survey to determine the use of water by this phreatophyte.

During the spring and summer of 1961 and 1962, growth (increase in length of branches) and development (increase in number of side shoots on these branches) were observed and recorded. The data so obtained could be correlated with the measured use of water and with accessibility to water.

Results of the studies follow. Saltcedar does not grow or develop in this area when the depth to water is 18 feet or more. Saltcedar tanks use more water with higher water tables, but there are no significant differences in growth or development if the depth to water is 9 feet or less. Saltcedar grows and develops fast in the early spring, with rapid increase in use of water; by mid-summer both growth and development level off sharply, with a drastic reduction in water use, even though accessibility of water remains the same.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 159

1966. Evaporation from vegetated and fallow soils. Water Resour. Res. 2(1): 99–103, illus.

Near Buckeye, Ariz., five evapotranspirometers were installed in the fall of 1962. Water losses from these tanks were measured; two of the tanks were planted to saltcedar and the other three kept bare. Rates of water loss from vegetated tanks plotted against time show a diurnal wave, with a maximum loss in the early afternoon of hot summer days. The losses from bare tanks so plotted show two maximums. The rate drops sharply during the middle of the day. Harmonic analysis reveals that the second harmonics of both curves are nearly identical in amplitude and phase angle. Later in the season the second harmonic of the vegetated tanks disappears. Certain unexplained anomalies remain in the analyzed data.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 160

1968. Effect of soil salinity on the loss of water from vegetated and fallow soil. *In* Water in the Unsaturated Zone, Symp. Wageningen, the Netherlands, June 19–25, 1966. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 83: 635–643.

In the semiarid zone of the Southwestern United States, some six million hectares near washes and along rivers are covered by a dense growth of riparian or phreatophytic vegetation, consisting very often of pure stands of saltcedar (*Tamarix pentandra*). This vegetation, having a nearly unlimited access to water, transpires large quantities of water, estimated to total over 29 x 10^9 cubic meters per year.

In order to measure the actual rate of evapotranspiration, six large evapotranspirometers (surface area about 80 square meters) were installed near Buckeye, Ariz., in 1959 and another five in 1962. In 1963 the salinity of the ground water in the older tanks (evapotranspirometers) had risen from an original 4 to over 200 parts per thousand. Although saltcedar is reported to tolerate and thrive on soil moisture of high salinity, the tanks were flushed out until the salinity of the effluent was back to the original concentration. Whereas in 1963 the water use varied between 80 and 200 cubic meters per tank per year (depending on depth to water in the tanks), after flushing the use increased by more than 50 percent.

It is frequently assumed, when water use by phreatophytes is estimated, that the plants have access to water of low salinity. The data presented in this paper show that this assumption may not always be right and that the actual water losses may be less than estimated by as much as 40 percent.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 161

1968. Water level fluctuation in evapotranspirometers. Water Resour. Res. 4(4): 761–768.

Eleven plastic-lined evapotranspirometer tanks were constructed near Buckeye, Ariz. The levels of the artificially maintained ground water in these instruments show distinct diurnal fluctuations. On bare tanks or on vegetated tanks that are not transpiring, this fluctuation is highly correlated with diurnal and semidiurnal atmospheric fluctuations. Two possible reasons for such response are discussed: There might be air bubbles in the saturated zone, or it might be caused by the flexible plastic lining of the tank. The barometric efficiency is about 40 percent. On vegetated tanks that are transpiring, the water level and barometric curves are out of phase, but if the water levels are corrected for atmospheric pressure fluctuations, a curve appears that represents the hourly rate of water use. The results may be important in the interpretation of transpiration-well data.—Auth abstr.

VAN HYLCKAMA, T. E. A. 162

1969. Photosynthesis and water use by saltcedar. Int. Ass. Sci. Hydrol. Bull. [Louvain] 14(1): 71–83.

Near Buckeye, Ariz., saltcedar (*Tamarix pentandra*) was grown on a battery of evapotranspirometers under various conditions of plant density, soil salinity, and access to water. Growth and development of the plants declined sharply at the beginning of each July, although before that time rates of growth and development had been very high. It was initially postulated that carbon dioxide might have become the limiting factor. Measurements of the carbon dioxide content of the air made at different heights inside and outside the evapotranspirometers, however, showed that this was not the case.

Analysis of the data shows a close correlation between carbon dioxide and water vapor fluxes (computed by means of mass transfer equations) above saltcedar thickets. A reduction of fluxes during hot afternoons appears to be due to ambient temperatures over 40° C. Water use is similarly affected.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 163

1970. Water use by saltcedar. Water Resour. Res. 6(3): 728–735.

Six years of observations on water use by saltcedar, conducted in a battery of evapotranspirometers, or tanks, have shown that thinned-out stands use nearly as much water as control tanks if the water is of good quality. It is concluded that the method of making a vegetation survey and then extrapolating water use as measured in evapotranspirometers to a 100 percent density can lead to serious overestimation of water use. Thinning and cutting are ineffective methods of saving water. In cutoff stands, under favorable conditions, shoots can increase in length by as much as 5 cm. per day. Only a few plants, such as bamboo and cucumber, are reported to grow faster than that.

The assumption that phreatophytes always transpire at a potential rate is not sustained by the facts presented in this paper. When differences in depth to water as small at 1.5 to 2.1 meters and 2.1 to 2.7 meters affect the water use, it seems reasonable to conclude that with a water table at 4 meters for instance (a situation not unusual along dry river beds), saltcedars still may thrive but use comparatively little water, and the claims as to the quantity of water potentially saved by their eradication could well be overestimated.—From auth. abstr.

VAN HYLCKAMA, T. E. A. 164

Water use by saltcedar in the lower Gila River Valley (Arizona). U. S. Geol. Surv. Prof. Pap., illus. (In press)

Studies of water use by saltcedar (*Tamarix pentandra*) were carried out during a 7-year period (1960–1967) near Buckeye, Arizona, using six plastic-lined evapotranspirometers.

With a depth to ground water of 5 feet, the average water use was about 85 inches per year; with a water table at 7 feet the use diminished to about 60 inches per year; and with a water table at 9 feet the yearly water use was less than 40 inches per year. Water use also decreased significantly as the salinity of the soil moisture increased.

When the vegetation was cut twice a year to a height of 18 inches, the water use decreased to about half that in tanks where the vegetation was not cut. Where the vegetation was thinned to 50 percent of the original, the water use diminished by only 10 percent.

The daily fluctuations of the water use from bare soil show that in the summer the evaporation at mid-day diminishes because of the formation of the vapor barrier, in contrast to water losses from the soil underneath a dense vegetation, where evaporation continues.—From auth. abstr.

See also 684.

Percolation Lysimeters

Thornthwaite Evapotranspirometers

CHAPMAN, L. J., AND LINTON, G. M. 165

1954. Summary report on controlled irrigation at the Orono Nursery. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 94–97, illus.

The first objective of the experimental work was to measure the total amount of water evaporated from the soil and transpired by the young trees in the seedbeds under conditions of adequate moisture, in order to check the validity of the Thornthwaite formula under these conditions. To do this, a pair of large pans 5 feet square and 30 inches deep were countersunk in one of the seedbeds and filled with soil to the level of the original surface.

The water used was less than the computed amounts in the first 2 years. During 1950 and 1951, when the seedlings were healthier and the water was added as surface sprinklings, the measured and computed values agreed very well.—From auth. introd.

GARNIER, B. J. 166

1954. Measuring potential evapotranspiration in Nigeria. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 140–176, illus.

The apparatus used in Nigeria was a simplified version of the Thornthwaite evapotranspirometer. The results show that, in this equatorial climate, such factors as solar radiation, cloud cover, and rainfall are more important in determining potential evapotranspiration than temperature.

GILBERT, M. J. 167

1954. Evapotranspiration measurements at Waynesville, North Carolina. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 52–54, illus.

Measurements of evapotranspiration were begun at Waynesville, N. C., as part of the data being collected on the hydrology of the mountain region of the State. Briefly, 55-gallon drums are sunk in the ground filled with soil,

and planted to a crop (in the present case, grass and clover). A space is provided in the bottom of the tank for collection of the percolate. Since maximum evapotranspiration is being measured, soil moisture must be maintained at tensions which do not limit rate of moisture uptake by the vegetation. This is done by irrigating from above. The criterion for irrigation is a moisture tension of 100 cm. of water, measured by a tensiometer placed at a 2-inch depth. Depth of percolate is measured with a dipstick through a 1-inch pipe.—From auth. introd.

GILBERT, M. J., AND VAN BAVEL, C. H. M. 168

1954. A simple field installation for measuring maximum evapotranspiration. Amer. Geophys. Union Trans. 35(6): 937–942.

Soil-filled 55-gallon gasoline drums have been used to measure maximum evapotranspiration at Waynesville, N. C. Installation involved no mechanical devices, and maintenance is at a minimum. Water is added manually to prevent water supply to the plants from becoming a limiting factor. Tensiometers are used to indicate when water must be added. Tanks are placed in the center of areas of the same vegetation. Data for one year under grass cover are presented and compared with values calculated from Thornthwaite's formula and Penman's formula. The latter appears, upon statistical analysis, to fit the data better than the former.—From auth. abstr.

GUERRINI, V. H. 169

1954. A year of evapotranspiration in Ireland. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 98–111.

This paper presents the results of an attempt to fit the formula for potential evapotranspiration as a function of temperature, devised by Thornthwaite, to observed evapotranspiration figures in Ireland. An evapotranspirometer of a simple type was installed. The study shows that the amounts of water lost by evapotranspiration agree very well with the figures expected from Thornthwaite's formula during spring, summer, and early autumn but disagree seriously in the months of November to February.—From auth. introd. and sum.

MCCLOUD, D. E., AND DUNAVIN, L. S., JR. 170

1954. Agrohydrologic balance studies at Gainesville, Florida. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 55–68, illus.

Water, even in humid climates, is being recognized as a major factor in crop production. In Florida, with around 50 inches of annual precipitation, droughts frequently occur. A quantitative knowledge of the rate of water movement from the soil and plant upward into the atmosphere is necessary to determine the agrohydrologic balance so important in crop yields. The purpose of the work underway at Gainesville is to measure the upward movement of water with various crops supplied adequate moisture, and to determine whether a relationship can be found between this water loss and any commonly measured meteorological factor. Early in 1952 modified potential evapotranspirometers were constructed to measure water loss with various crops.—From auth. introd.

MATHER, JOHN R. (ed.) 171

1954. The measurement of potential evapotranspiration. The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 255 p.

This publication includes a number of papers dealing with the measurement of potential evapotranspiration in many different climatic regions. Although it is too early for a comprehensive analysis of all the information included in it, still it is desirable to bring together a few of the more

pertinent observations and conclusions of the various authors in an effort to evaluate the evapotranspirometer as an instrument to measure potential evapotranspiration and the empirical Thornthwaite formula for computing evapotranspiration. Final conclusions concerning these and other objectives must await more information and a more careful analysis of the available data.—From auth. sum.

MATHER, JOHN R. 172

1954. A summary of evapotranspiration at Seabrook, New Jersey 1947–1953. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 7–51, illus.

Knowledge of the distribution of moisture in the atmosphere and soil will provide a more fundamental understanding of problems in many fields of endeavor. The concept of potential evapotranspiration, introduced some years ago by Thornthwaite, aids greatly in the comprehension of the moisture factor and its relation to other climatic parameters. Thornthwaite used the rather limited observational data to derive a formula from which the actual water need at a place can be computed from readily available climatic data. Several kinds of information have been used to test the reliability of the formula. Obviously, the best check of the formula and of the concept of potential evapotranspiration would be to measure water need experimentally. Investigations have shown that the use of a vegetation-covered, soil-filled tank provides the most satisfactory method of making the necessary measurements.—Auth. introd.

RAMAGE, C. S. 173

1954. Evapotranspiration measurements made in Hong Kong. First Report, October 1951 to May 1953. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 112–124, illus.

In Hong Kong, where irrigation of winter crops is unavoidable, a knowledge of water requirements for healthy plant growth is essential if best use is to be made of the limited water resources of the Colony. To determine the validity for Hong Kong of Thornthwaite's empirical formula, a rough preliminary test was made for Island and Mainland reservoir catchment areas.

It was concluded that the formulae have little application in Hong Kong, a not unexpected result, since almost all the stations Thornthwaite lists as showing a close relation between actual and calculated potential evapotranspiration experience dry, water-deficient summers and moist water-surplus winters, whereas the distribution in Hong Kong, being monsoonal, is just the reverse.

It was obvious that if any reliable data on potential evapotranspiration in Hong Kong were to be obtained, direct measurement would be necessary, and so it was decided to construct an "evapotranspirometer" which enables direct measurement of potential evapotranspiration to be made. Results are given in the report.—From auth. introd.

SANDERSON, MARIE 174

1948. An experiment to measure potential evapotranspiration. Can. J. Res. [Ottawa] 26C(4): 445–454.

A method of obtaining daily values of the potential evaporating power of the atmosphere was used for the first time in Canada in 1947. The results verify Thornthwaite's formula for computing potential evapotranspiration in southern Ontario. The correlation between average runoff and computed water surplus for several watersheds in Ontario and Quebec is presented on a map.—Auth. Abstr.

SANDERSON, MARIE 175

1950. Moisture relationships in southern Ontario. Sci. Agr. [Ottawa] 30(6): 235–255, illus.

SANDERSON, MARIE 176

1950. Measuring potential evapotranspiration at Norman Wells, 1949. Geogr. Rev. 40(4): 636–645.

The first season's results from the two evapotranspirometers at 65° N. seem to indicate that extrapolation poleward in the use of the Thornthwaite formula gives results of the right order of magnitude.

SANDERSON, MARIE 177

1950. Three years of evapotranspiration at Toronto. Can. J. Res. [Ottawa] 28C(5): 482–491.

An experiment to measure the daily potential evapotranspiration from vegetation-covered soil surfaces was conducted in Toronto during the 1947, 1948, and 1949 growing seasons. The potential evaporation from moist bare soil was also measured and compared with the evaporation from dry soil. Results indicate that the Thornthwaite formula for computing potential water loss is valid at this latitude for both vegetation-covered and moist soil. When drying of the surface soil occurred, the water loss was diminished.—Auth. abstr.

SANDERSON, MARIE 178

1954. Measuring potential evapotranspiration, Toronto, 1947, 1948, 1949. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 69–83, illus.

SANDERSON, MARIE 179

1954. Measuring potential evapotranspiration—Norman Wells, Northwest Territories, Canada, 1949, 1950. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 84–90, illus.

Since the Thornthwaite formula for determining potential evapotranspiration was developed from midlatitude data, it was felt that the establishment of an evapotranspirometer station at a high latitude in Canada would determine the validity of poleward extrapolation of the Thornthwaite formula. Norman Wells in the Northwest Territories (64°50′ N, 125°20′ W) was chosen as the location of the experiment, since summer temperatures are considerably higher and the depth of permafrost less in the Mackenzie Valley district of northwestern Canada than at similar latitudes in the east. The data collected from the evaporimeters indicate that extrapolation poleward in the use of the Thornthwaite formula gives results in the right order of magnitude.

SANDERSON, MARIE 180

1954. Observations of potential evapotranspiration at Windsor, Ontario, 1953. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 91–93.

Two evapotranspirometer tanks, of the type developed by the Johns Hopkins University Laboratory of Climatology and known as modified evapotranspirometers, were installed in May 1953 in a lawn area in South Windsor, Ontario, Canada (latitude 42°17′ N, longitude 82°58′ W.).

SMITH, G. W. 181

1954. Evapotranspiration in Trinidad, B.W.I. *In* The Measurement

of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol. 7(1): 125–139, illus.

THORNTHWAITE, C. W. 182

1954. A re-examination of the concept and measurement of potential transpiration. *In* The Measurement of Potential Evapotranspiration. Mather, John R. (ed.). The Johns Hopkins Univ. of Climatol. Pub. in Climatol. 7(1): 200–209, illus.

While determining the water requirements for irrigation in Mexico in 1944, the author realized that one could not determine the amount by which precipitation fails to supply water needs for crops unless the water needs are known. This most important climatic element was called potential evapotranspiration. It was computed by means of an empirical formula involving mean monthly temperature and relative humidity. In refining this formula to achieve more satisfactory results and to utilize only climatic data which are generally available, the author dropped the humidity term and only mean temperature and average length of day were utilized. This potential evapotranspiration concept allowed a more rational interpretation of the moisture factor in climate to become available. The actual evapotranspiration and water deficit could be determined and the water surplus and runoff evaluated.

Various independent means of determining potential evapotranspiration for the purpose of verifying and modifying the formula were sought. In 1946 an instrument called an evapotranspirometer was put into service by the Mexican Irrigation Commission.

Since 1946 collaborators in every continent have installed evapotranspirometers, and observations are beginning to accumulate in various climatic regions. It is important to re-examine the design of the instrument and the methods of operation in an attempt to assess the reliability of the observations. It is also important to re-examine the concept and definition of potential evapotranspiration and to determine whether or not the evapotranspirometer really measures potential evapotranspiration.—From auth. introd.

THORNTHWAITE, C. W., AND MATHER, J. R. 183

1955. Potential evapotranspiration. *In* The Water Balance. Drexel Inst. of Tech. Lab. of Climatol. Pub. in Climatol. 8(1):14–21.

The measurement of both potential and actual evapotranspiration is an extremely complex undertaking. The evapotranspirometer, when operated properly, i.e., when watered sufficiently so that there is no moisture deficiency and no appreciable moisture surplus in the soil in the tank, and when exposed homogeneously within a protective buffer area of the proper size to eliminate the effect of moisture advection, is an instrument which should give reasonably reliable values of potential evapotranspiration. Great care must be taken in the operation of the instrument; standardized soil, vegetation, cultivation, and watering practices must be maintained on the tanks in order to insure realistic observations which are comparable from one installation to another.—From auth. sum.

See also 140, 523.

Miscellaneous

COLMAN, E. A., AND HAMILTON, E. L. 184

1947. The San Dimas lysimeters. U. S. Dep. Agr. Forest Serv. Calif. Forest and Range Exp. Sta. Res. Note 47, 33 p.

Lysimeters were installed on the San Dimas Experimental Forest, in California, in 1937 for the purpose of comparing the water economy of a number of chaparral plant species that are important in the management

of southern California mountain watersheds. The installation includes several types of lysimeters and a climatic station, located on an area of uniform topography and enclosed by a rodent-proof and deer-proof fence. The same kind of soil has been used and uniformly placed in all the lysimeters in order to minimize soil variability. Rain, runoff, and seepage are measured, and weighing or periodic soil-moisture sampling is used to study evaporative water losses.

This paper describes the four types of lysimeters included in the San Dimas installation. The authors compare data from them to learn whether it is possible to use one type of lysimeter to provide data to supplement those obtained in another type.

EL NADI, A. H., AND HUDSON, J. P. 185

1965. Effect of crop height on evaporation from lucerne and wheat grown in lysimeters under advective conditions in the Sudan. Exp. Agr. [London–New York] 1(4):289–298.

A simple but reliable type of drainage lysimeter was used to measure evaporation rates from lucerne (alfalfa) and wheat, and these were compared with calculated estimates of evaporation. Plant height was found to have an important effect on the amount of water lost from a plant cover. The amounts of water lost from two different species of crop of similar heights varied. When two different types of soil were used and maintained at a high moisture status, the rate of water loss was not influenced by the type of soil in which the plants were grown.—From auth. sum.

KLAUSING, O. 186

1965. The determination of the evaporation from the plant cover and the surface of the soil by relating lysimeter and soil moisture measurements to potential evaporation. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 461–465.

PATRIC, JAMES H. 187

1961. The San Dimas large lysimeters. J. Soil Water Conserv. 16(1): 13–17, illus.

Twenty-six lysimeters installed in 1937 on the San Dimas Experimental Forest, in California, compare water losses and yields under several plants native to the chaparral-covered mountains of southern California. Local, uniformly mixed soil was placed in concrete tanks, 10.5 feet by 21 feet by 6 feet deep, each drained by a parallel top and bottom slope of 5 percent. Surface runoff and seepage are measured for each unit. Soil moisture is measured at uniform depths in several lysimeters with Colman electrical resistance units. A climatic station is on the site.

The research program was developed in three stages: (1) The soil settlement period, (2) the grass cover period, and (3) the long-term native species test period, which began in 1946.

Soil settlement under a protective excelsior cover was completed by 1940. A 6-year calibration period followed, when 25 of the lysimeters were seeded to grass. The soil in one unit was left bare and has remained bare since 1940.

In 1946 the grass cover was replaced in 23 lysimeters by four chaparral species and Coulter pine. Two lysimeters contained grasses. During tests made in the period 1952–56, the significant results indicated that water yield was entirely surface runoff, except for a small amount of seepage under grass cover. Woody plants used all available moisture, while 10 inches of moisture remained under bare and grass-covered soils. During the winter and spring, pine and grass dried the soil faster than scrub oak. During a season of high rainfall (48.4 inches), evapotranspiration losses

were computed as follows: Bare soil, 8.7 inches; grass, 16.0 inches; pine, 25.1 inches; chamise (*Adenostoma*), 25.5 inches; and scrub oak, 24.8 inches; buckwheat, 24.3 inches; and ceanothus, 23.6 inches.

PATRIC, JAMES H. 188

1961. A forester looks at lysimeters. J. Forest. 59(12): 889–893, illus.

Despite their usefulness in agriculture, lysimeters have found little use in forestry. One reason is that plants grown in lysimeters tend to be smaller than those grown nearby under more natural conditions because root systems cannot expand normally. This paper reports studies which indicate that lysimeters can aid forestry research if application of the data is treated with due caution.

Comparisons of the crowns of Coulter pine trees growing in the lysimeters on the San Dimas Experimental Forest, in California, with those growing in the surrounding area show a much reduced growth for the former. The conclusion is inescapable that lysimeters are a poor place for raising trees. Is there, then, a place for lysimeters in forestry research? Undoubtedly there is, but data from their use must be treated with great caution. Results derived from growing trees in lysimeters will necessarily be based upon plants smaller and less vigorous than those expected to survive under natural competition.

The use of lysimeters may, however, adequately fulfill certain functions in forestry research. Probably no better way is known to determine or compare rates of water use by plants, including relatively small trees.—From auth. introd. and sum.

RICH, L. R. 189

1959. Hydrologic research using lysimeters of undisturbed soil blocks. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys. Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49:139–145.

The Base Rock lysimeters of the Sierra Ancha Experimental Watersheds in central Arizona afford an unusual opportunity for studying surface and percolation flow in relation to precipitation and vegetational densities in a natural soil mantle.

The installation consists of three lysimeters, 5.5 meters wide and 15.2 meters long, having a south-facing slope of 20 percent at 1,219 meters elevation. Undisturbed soil blocks 0.9 to 1.8 meters deep are surrounded by cement walls which are tied into impervious quartzite bedrock.

Data from the lysimeters have shown that: (1) Subsurface runoff is an important portion of total water yields; (2) most of the total water yield results from percolation flow during the winter; (3) most surface runoff and erosion are associated with high intensity thunderstorms during the summer; (4) surface runoff and erosion increase as grass densities decrease; and (5) winter water yields appear to be independent of vegetational densities.—From auth. abstr.

SARTZ, RICHARD S. 190

1963. Water yield and soil loss from soil-block lysimeters planted to small trees and other crops, southwestern Wisconsin. U. S. Dep. Agr. Forest Serv. Lake States Forest Exp. Sta. Res. Pap. LS–6, 23 p., illus.

Surface runoff, percolation, and soil loss from lysimeters with different cover were measured for 6 years. Mulched tree seedlings and grass yielded little runoff and soil during the growing season, while unmulched seedlings and grain yielded large amounts. Differences by cover type were less distinct in the dormant season. Most of the percolation occurred during the dormant season. Annual variation was high in both seasons.—Auth. abstr.

SINCLAIR, J. D., AND PATRIC, J. H. 191

1959. The San Dimas disturbed soil lysimeters. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 116–125, illus.

This paper highlights some problems of establishing and operating lysimeters and presents some preliminary results.

Compared to bare soil, all vegetation markedly decreased surface runoff and correspondingly increased infiltration. Evapotranspiration from vegetated soil was two to three times greater than from the bare lysimeter. Grass-covered soils yielded the most seepage.—From auth. sum.

STANHILL, G. 192

1964. Potential evapotranspiration at Caesarea. Israel J. Agr. Res. [Rehovot] 14(4): 129–135, illus.

Measurements of potential evapotranspiration in the central coastal plain of Israel were taken for 3 years from grass-covered lysimeters situated on a golf course and receiving daily irrigation. The mean values obtained were compared with evaporation from an open water surface, estimated by Penman's method and measured with a class *A* pan. A high correlation was found between the mean monthly water losses from the two surfaces, and after considering the effects of soil and other environmental factors, it was utilized in calculating the water requirements for summer irrigation of lawns growing in the main urban areas of Israel.—From auth. abstr.

VAN BAVEL, C. H. M., AND HARRIS, D. G. 193

1962. Evapotranspiration rates from bermudagrass and corn at Raleigh, North Carolina. Agron. J. 54(4): 319–322, illus.

Evapotranspiration of Bermudagrass and corn was measured with lysimeters at Raleigh, N. C., over three growing seasons. The Penman formula in three modifications accounts reasonably well for the observed values. Roughly, evapotranspiration was equivalent to 0.8 of net radiation over the crop.—Auth. abstr.

ZINKE, PAUL J. 194

1959. The influence of a stand of *Pinus coulteri* on the soil moisture regime of a large San Dimas lysimeter in southern California. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 126–138.

See also 22, 53.

Weighing Lysimeters

Coshocton, Ohio

DREIBELBIS, F. R., AND AMERMAN, C. R. 195

1964. Land use, soil type, and practice effects on the water budget. J. Geophys. Res. 69(16): 3387–3393, illus.

Analyses of data from lysimeters and small watersheds near Coshocton, Ohio, indicate the effects of various soil and agronomic factors on the magnitude of the several elements of the water budget. From lysimeter data, the effects of soil types and agronomic practices upon the magnitude of evapotranspiration are shown for corn, wheat, and meadow in a 4-year rotation. From small-watershed data, the magnitudes of evapotranspiration from various parts of the profile of Muskingum soils with covers of corn, pasture, and woods are indicated. Data for a 5-year period showed that, on

similar soils, areas with a cover of shallow-rooted poverty grass had greater percolation and runoff and less evapotranspiration and water-use efficiency, than areas with a cover of deep-rooted birdsfoot trefoil.—Auth. abstr.

HARROLD, L. L., AND DREIBELBIS, F. R. 196

1951. Agricultural hydrology as evaluated by monolith lysimeters. U. S. Dep. Agr. Tech. Bull. 1050, 149 p., illus.

This bulletin is a progress report to 1949 on the lysimeter investigations carried on at the North Appalachian Experimental Watershed, near Coshocton, Ohio.

HARROLD, L. L., AND DREIBELBIS, F. R. 197

1958. Evaluation of agricultural hydrology by monolith lysimeters, 1944–55. U. S. Dep. Agr. Tech. Bull. 1179, 166 p., illus.

This bulletin is a progress report on the lysimeter investigation carried on at the Soil and Water Conservation Research Station near Coshocton, Ohio, from 1944 through 1955. Summaries of percolation data are presented for the period 1938–55.

The hydrologic data were obtained from 11 monolith lysimeters, each 0.002 acre in area and 8 feet deep, three of which were weighed automatically every 10 minutes. The features of the installations are described briefly. Percolation from the soils into cracks and crevices of the rock at the 5-foot depth takes place naturally without supplying extra tensions. Records of the percolation water collected at the 8-foot depth, along with records of precipitation and runoff, are presented in tables and graphs for each lysimeter. Weight records provided data for determination of moisture storage changes in the soil monolith. Daily gains in weight not associated with periods of precipitation were designated as condensation and absorption.

The amount of moisture condensed and absorbed was fairly large, ranging from 6 to 10 inches of water annually. Although this moisture, or dew, may be entirely evaporated in the morning hours, its value in conserving soil-moisture supplies is notable.

Soil moisture depletion by evapotranspiration was greatest in May, June, July, and August. Stage of crop growth, that is, development of leaf area and maturity, as well as depth of root penetration and available soil moisture, affected evapotranspiration values. With normal precipitation, evapotranspiration values averaged from about 80 to 90 percent of the annual supply. In years of deficient precipitation, evapotranspiration used about 96 percent of the supply.—From auth. sum.

HARROLD, L. L., AND DREIBELBIS, F. R. 198

1964. Evidence of errors in evaluation of dew amounts by the Coshocton lysimeters. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 65: 425–431.

The amount of dew reported in the earlier publications on the lysimeters near Coshocton, Ohio, has been found to be too large because of an instrumental error which resulted in erroneous readings. This error affects readings for a single day but does not detract from most of the information included in the U. S. Department of Agriculture Technical Bulletins that reported on these lysimeters. (Harrold and Dreibelbis 1951, 196 and 1958, 197).

HARROLD, L. L., AND DREIBELBIS, F. R. 199

1967. Evaluation of agricultural hydrology by monolith lysimeters, 1956–62. U. S. Dep. Agr. Tech. Bull. 1367, 125 p., illus.

This bulletin is a progress report on the lysimeter investigations carried on at the North Appalachian Experimental Watershed, near Coshocton, Ohio, from 1956 through 1962. Summaries of moisture balance studies are

presented for 1944–62. Data for 1944–55 represent, in part, a revision of those published in U. S. Department of Agriculture Technical Bulletin 1179 [Harrold and Dreibelbis 1958, 197].

The hydrologic data were obtained from 11 monolith lysimeters, each 0.002 acre in area and 8 feet deep, three of which were weighed automatically every 10 minutes. The features of these unique installations and the history of their operation have been described in U. S. Department of Agriculture Technical Bulletin 1179. Review of lysimeter literature during 1944–55, given in that bulletin, is extended to 1962 in the present report.

The basic research plan developed in 1935 for the North Appalachian Experimental Watershed near Coshocton, Ohio, provided for evaluation of all factors affecting the disposal of precipitation, as part of a comprehensive study designed to uncover basic laws relating to agricultural hydrology. Lysimeters were considered an important part of the instrumentation necessary for this study. Rainfall and runoff measurements provided data for the determination of infiltration. Percolation data were related to recharge of ground water. Weight-change records adjusted for amounts of rainfall, runoff, and percolation provided data on evapotranspiration. All these values were necessary in the analysis and interpretation of the station's watershed records.

Because of the climatic variables, there were times when soil moisture was sufficient to meet crop needs and times when it was not. For the 1956–62 period, annual precipitation was above normal for 3 years and below normal for 4 years. The extremes of annual precipitation for this period were 53.40 inches in 1959 and 36.32 inches in 1958. Thus, evaluation of the data on agricultural hydrology in this bulletin reflects sizable variations in climate.—Auth. introd.

HARROLD, L. L., PETERS, D. B., DREIBELBIS, F. R., AND MCGUINNESS, J. L. 200
1959. Transpiration evaluation of corn growth on a plastic-covered lysimeter. Soil Sci. Soc. Amer. Proc. 23(2): 174–178.

Corn grown on plastic-covered monolith lysimeters near Coshocton, Ohio, showed that a very good crop was produced by using only the water stored in the soil. A yield of 125 bushels per acre was obtained by using only 8.5 inches of water from the soil. For the entire growing season, May 1 to September 9, it was estimated that the evapotranspiration would be composed of 56 percent evaporation and 44 percent transpiration. Thus, water use efficiency was greatly increased by use of the plastic cover because loss of water by evaporation was eliminated.—From auth. abstr.

MUSTONEN, SEPPO E., AND MCGUINNESS, J. L. 201
1967. Lysimeter and watershed evapotranspiration. Water Resour. Res. 3(4): 989–996, illus.

A statistical model was derived for permanent grass lysimeter evapotranspiration (ET_L) [near Coshocton, Ohio,] using lake evaporation, soil moisture, and precipitation as independent variables. Measured annual ET_L was substantially greater than evapotranspiration derived from water budget estimates on small watersheds. Differences in the ET_L rate for permanent grass and grain crops were greatest at grain planting time when the ground was bare. ET_L fell to about one-half of normal when hay was cut and recovered to normal in about one month.—Auth. abstr.

PETERS, D. B. 202
1960. Relative magnitude of evaporation and transpiration. Agron. J. 52(9): 536–538.

The relative magnitude of soil evaporation and transpiration cannot be established as a precise ratio since the magnitude of each is dependent upon the relative wetness of the surface.

Evidence presented in this paper indicate that in the Midwest [where the Coshocton, Ohio, lysimeters were established], where frequent summer

showers occur, as much as 50 percent of the total water loss in a season can be accounted for by evaporation from the soil surface.

Plastic-covered plots have consistently yielded a value of from 5 to 9 inches of water use, regardless of location or year. It thus appears that the amount of transpiration from a particular crop is within rather narrow limits.

It has been established that in row crops sufficient energy reaches the ground surface to account for a considerable portion of the water loss. The absolute amount of water loss is, however, dependent upon the time the soil surface is wet and upon the moisture-holding and transmitting capacities of the soil. It would be virtually impossible to predict the absolute amount of soil evaporation.—From auth. sum.

RIESBOL, HERBERT S., AND SHERMAN, GEORGE L. 203

1938. Watercycle lysimeters for watershed studies. Agr. Eng. 19(3): 123–128, illus.

Watercycle lysimeters being built for watershed studies by the U. S. Soil Conservation Service at Coshocton, Ohio, are described in detail.

See also 134, 140, 571.

Davis, Calif.

PRUITT, W. O. 204

1960. Correlation of climatological data with water requirement of crops. Calif. Univ. Davis Dep. Irrig. Annu. Rep. 1959–60, 91 p., illus. Processed.

The results of research on the correlation of climatological data with water requirements of crops are brought up to date in this report.

With completion of a large weighing lysimeter at Davis in the spring of 1959, almost continuous evapotranspiration data were obtained for a crop (ryegrass) which was at all times providing nearly full cover. Daily totals from June 1, 1959, through May 31, 1960, are given.

Results of brief energy-balance studies made in February 1960 are presented along with a discussion of some of the problems in using the energy balance.

Analysis of the correlation of evaporation from various devices with evapotranspiration of ryegrass indicates a high correlation, even for daily comparisons, but also shows a serious change in the relationships under strong, dry north wind conditions. Local environment is shown to be a very important factor in such relationships.

Daily estimates based on three procedures (Penman, Blaney-Criddle, and Thornthwaite) are compared with daily lysimeter losses, with a good correlation shown for all three cases.

Accumulation of moisture from the atmosphere in the form of dew was very small in magnitude. Approximately one-quarter of an inch of water was accumulated on a ryegrass cover over a 12-month period from June 1959 through May 1960.—From auth. abstr.

PRUITT, W. O. 205

1964. Cyclic relations between evapotranspiration and radiation. Amer. Soc. Agr. Eng. Trans. 7(3): 271–275, 280.

Seasonal and diurnal relationships between evapotranspiration and radiation and air temperature were developed; data from the lysimeter at Davis, Calif., were used.

PRUITT, W. O., AND ANGUS, D. E. 206

1960. Large weighing lysimeter for measuring evapotranspiration. Amer. Soc. Agr. Eng. Trans. 3(2): 13–15, 18.

The lysimeter built at Davis, Calif., in 1958–59 was 20 feet in diameter and 3 feet deep. Changes in evaporation are read to an accuracy to 0.0012

inch. The tank was separated from the surrounding area by only 1.25 inches. A drainage system was designed to remove excess soil water. Free water drained through perforated plastic tubes placed in a sand layer on the bottom. A grid of ceramic tubes, connected to a vacuum system, removed excess water.

PRUITT, W. O., AND LOURENCE, F. J. 207

1968. Correlation of climatological data with water requirements of crops. Calif. Univ., Davis. Dep. Water Sci. and Eng. Pap. 9001, 59 p., illus.

The two grass crops used in recent studies at Davis have been grown largely to serve as a year-round standard for evapotranspiration from a short, smooth, actively growing crop. The first crop grown in the large weighing lysimeter at Davis (Pruitt and Angus 1960, 206) was perennial ryegrass; records extend from June 1959 through December 1963. Data were first obtained on a crop of alta fescue grass in June 1964 and have continued.

With a Bowen-ratio system located in an alfalfa field, tests in March 1967 showed water losses by alfalfa (only 6 inches tall) to be 90 percent of the loss by alta fescue grass. In May, with tall alfalfa ready for cutting, the Bowen-ratio system indicated alfalfa water losses exceeding fescue water losses by an average of 14 percent. Other tests in early May, with the Bowen-ratio measurements made over the grass field, gave results similar to those obtained with the lysimeter which was in grass. Especially encouraging was the close prediction of actual evapotranspiration, even during 2 of the days with high variable cloudiness.

Tests of a modified combination aerodynamic-energy balance equation showed remarkable predictive capability hour by hour under climatic conditions ranging from cool, cloudy weather to very hot, clear weather,

Two seasons' lysimeter determinations of evapotranspiration by sugar beets and tall fescue grass are compared. In 1966, the sugar beets averaged 10 percent more water use than grass from the time 80–90 percent cover had developed to the time of harvest. For an 8-week midseason period, however, the average loss by beets was 15 percent greater than that by the grass.

Daily data for 3 years of evapotranspiration by the alta fescue grass, along with solar radiation data and evaporation from a U. S. Weather Bureau class *A* pan, are also presented. Monthly totals and means for the earlier 4-year study with perennial ryegrass are provided for comparison, along with evaporation and solar radiation data. Evapotranspiration by the two species of grasses was closely comparable on an annual basis (51.86 inches for tall fescue and 52.63 inches for ryegrass).

In relation to pan evaporation, results were less variable for the fescue study than for the earlier study, largely because of a less drastic effect of strong advection conditions on transpiration by the fescue grass. Thus, it is considered as a superior crop for use as a standard for studies of potential evapotranspiration.—From auth. sum.

See also 25, 602, 610.

Phoenix, Ariz.

FRITSCHEN, L. J., AND VAN BAVEL, C. H. M. 208

1963. Experimental evaluation of models of latent and sensible heat transport over irrigated surfaces. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 159–171.

Research on evaporation—including plant transpiration—from irrigated land in a hot, arid climate and the related atmospheric processes is conducted at the U. S. Water Conservation Laboratory under three headings. First, the evaporative flux is measured directly with lysimeters. Second,

theories and instrumentation are examined for the purpose of estimating the fluxes of water vapor and sensible heat by aerodynamic and energy balance techniques. Third, techniques and instrumentation developed are used to obtain estimates of the fluxes under field conditions.

Facilities include an installation of three automatic weighing-type lysimeters and two 49-channel micrometeorological data-handling systems—one permanently mounted for use with the lysimeter installation and the other in a self-contained trailer to record micrometeorological variables in remote areas.

Research completed to date has been limited to evaporation from bare-soil and free-water surfaces. The results indicate that the best estimates on sensible and latent heat were obtained with Bowen's and Sheppard's equations, that evaporation from wet bare-soil and water surfaces may be estimated with identical one-level models, that aerodynamically calculated values of sensible heat flux are not constant with height, and that sensible heat advection at the surface was usually minor.—From auth. abstr.

Compiler's Note.—The lysimeters referred to in this section were built by the U. S. Agricultural Research Service at the U. S. Water Conservation Laboratory situated between Tempe and Phoenix, Ariz. Originally, the Post Office address was Tempe and in much of the literature they are called "the Tempe lysimeters". Recently, however, the address was changed to Phoenix, Ariz., and therefore, they should be listed as the "Phoenix lysimeters".

ROSENBERG, N. J., AND BROWN, K. W. 209

1969. Improvements in the van Bavel-Myers weighing lysimeters. *In* Research in Evapotranspiration: Energy Sources for Evapotranspiration in the Plains Region. Nebr. Univ. Coll. Agr. and Home Econ. Hort. Progr. Rep. 73: p. 1–6, illus.

Two precision weighing lysimeters of the type developed by van Bavel and Myers (1962, 211), at Phoenix, Ariz., were installed at Mead, Nebr. during the summer of 1966. Certain modifications of the original design were specified because of experiences by the staff at Phoenix. In the course of operations subsequent to installation, certain difficulties and failures occurred which necessitated further changes in the lysimeters. With the incorporation of these changes, the lysimeters function within the original specifications.—From auth. introd.

VAN BAVEL, C. H. M., FRITSCHEN, L. J., AND REEVES, W. E. 210

1963. Transpiration by sudangrass as an externally controlled process. Science 141(3577): 269–270.

Transpiration from a well-watered sudangrass stand in a highly evaporative environment (Phoenix, Ariz., in July) can be considerably increased by exposing a small plot of about 1 square meter to radiative and convective heat input. Thus, the transpiration of sudangrass in a full stand appears not to be determined by any physiological factor during any time of the day.—Auth. abstr.

VAN BAVEL, C. H. M., AND MYERS, L. E. 211

1962. An automatic weighing lysimeter. Agr. Eng. 43(10): 580–583, 586–588.

A description is given of a weighing lysimeter installation that records its weight, as measured by strain gages, automatically on punched paper tape. The precision of weighing is between 10 and 20 grams in a total weight of about 3,000 kg., equivalent to 0.01 and 0.02 mm. of water. The entire system is electronic with remote recording, leaving the site of measurement without serious disturbance. The record can be used directly in a tabulating typewriter or a machine computer.

The lysimeters are 1 square meter in area and 1.5 meters deep. They are provided with a vacuum-filter device in the bottom to insure normal

drainage. Operation of the system of three separate lysimeters was satisfactory over a period of a year. Wind may affect the performance of the lysimeters, but the disturbance is largely eliminated by the method of collecting and handling the weight data.

Some results of the lysimeters near Phoenix, Ariz., are given. Hourly values of weight define the diurnal fluctuations as well as 5-minute intervals. If the lysimeter where sudangrass was growing was well buffered by surrounding vegetation, its maximum reading for water loss was 0.39 inch per day. Isolated lysimeters reached 0.58 inch per day—From auth. sum.

VAN BAVEL, C. H. M., AND REGINATO, R. J. 212

1965. Precision lysimetry for direct measurement of evaporation flux. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 129–135.

This article describes the precision automatic weighing lysimeter installation of the U. S. Water Conservation Laboratory, outlining the mechanical and electrical features in some detail, and presents examples of the performance of the system.

The installation, 5 km. west of Tempe, Ariz., consists of a triplicate set of lysimeters located approximately in the center of a field 91 by 73 meters in area, each lysimeter being 1 square meter in area, spaced approximately 14 meters apart. The soil of the site is loam, a relatively recent and undeveloped alluvium of the Salt River. It is uniform, both chemically and physically, to a depth of 2 meters, and can be reconstituted artificially without undue difficulty. Thus, it was not considered necessary to attempt the construction of monolith lysimeters.

See also 25, 388, 641, 646, 647, 659.

Miscellaneous

ARTHUR, I. P. 213

1955. An evapotranspirometer. Aust. J. Agr. Res. [Melbourne] 6(5): 707–712, illus.

The equipment described in this paper is designed to measure evapotranspiration from a growing crop. It comprises a large container, filled with soil and set in a field so that the top is flush with the ground surface, and a device for measuring changes in weight of the contents. The crop in the container is, therefore, grown under conditions which closely approximate those in the surrounding field.—From auth. sum.

ENGLAND, C. B., AND LESESNE, E. H. 214

1962. Evapotranspiration research in western North Carolina. Agr. Eng. 43(9): 526–528, illus.

A weighing lysimeter was used in western North Carolina in hydrologic studies on several watersheds. A drum (25 inches in diameter) of soil was mounted on a beam scale equipped to print the weight at regular time intervals.

HAND, D. W. 215

1968. An electrically-weighed lysimeter for measuring evaporation rates. Agr. Meteorol. [Amsterdam] 5(4): 269–282, illus.

An electrically-weighed lysimeter using electrical resistance strain gages has been developed in Great Britain to measure the daily and diurnal rates of evaporation of water from crop or soil surfaces or both. The lysimeter, with a plan area of 0.4 m^2, records changes of weight of the order of 20 grams (equivalent to 0.05 mm. depth of water) over a range of 20 kg. in a total weight of 110 kg. Continuity of vegetation between the lysimeter and the surrounding area is facilitated by confining the weighing mechanism to the space directly beneath the container.

The weighing device consists of a mechanical system that supports the soil container and offsets a predetermined proportion of its weight and an electrical system that registers changes in load as changes in electrical output. The changes in load are transmitted to the sensing elements of a load transducer consisting of two machined aluminum weighbars that become loaded as beams after filling the lysimeter with soil. Each weighbar has a simple cantilever at either end, to which electrical resistance strain gages are affixed. The strain gages are wired into a Wheatstone bridge circuit, and the output is registered on a digital voltmeter or potentiometric chart recorder or both. The output voltage changes by an amount that is proportional to the change in load. Fifteen of these load cell lysimeters have been installed in a vinery-type greenhouse.—From auth. sum.

LIBBY, F. J., AND NIXON, P. R. 216

1963. A portable lysimeter adaptable to a wide range of site situations. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62:153–158.

An inexpensive portable weighing lysimeter, which is very sensitive and precise, has been built and put in operation. The lysimeter tank is 4 feet in diameter and 4 feet deep and weighs 5,000 pounds when full of soil. It can be used to measure, by weight, soil-plant moisture changes in a variety of environments, including flat flood-irrigated land or sloping terrain. Ninety percent of the soil tank weight is supported by a constant-force, counterweighted counterlevel system. The remaining 10 percent of the weight is supported and weighed by an electronic load-sensing device called a load cell. The load cell reflects weight changes by electrical resistance changes acting on a current passing through its circuitry. Small weight changes are observable and can be recorded or read periodically. The sensitivity of the lysimeter-weight change is equivalent to 0.001 inch water depth.—From auth. sum.

MCILROY, I. C. 217

1958. A lysimeter installation at Aspendale. *In* Climatology and Microclimatology. Canberra Symp. [Canberra, 1956] Proc. UNESCO Arid Zone Res. [Paris] 11: 45–47.

This report describes the installation of large weighed lysimeters in order to investigate potential evapotranspiration, behavior of specific vegetation, and related problems in Aspendale, Australia. This initial installation comprises 12 double containers made from standard reinforced concrete pipes by the addition of concrete bottoms. The soil within the lysimeters is 1.1 meters in depth, 2.0 square meters in area (1.6 meters in diameter), and 0.25 meter radial distance from the natural surroundings.

MCILROY, I. C., AND ANGUS, D. E. 218

1964. Grass, water and soil evaporation at Aspendale. Agr. Meteorol. [Amsterdam] 1(3): 201–224, illus.

Results are presented of the first 3 years of operation of a multiple, large weighed lysimeter installation. Evaporation from well-watered grass (potential evaporation) consistently exceeded that from free water and exceeded even more that from wet soil. The latent heat of potential evaporation also consistently exceeded net radiant energy available. These phenomena arise from the well-known oasis effect, operating on a very large scale and affecting rough surfaces more than smooth. Potential evaporation from grass is well correlated with water loss from several types of containers and with evaporation computed from meteorological observations by a recent formula. This suggests the desirability of using lysimeters to calibrate simpler methods of determining evaporation for subsequent routine use.—From auth. sum.

McIlroy, I. C. and Sumner, C. J. 219

1961. A sensitive high-capacity balance for continuous and automatic weighing in the field. J. Agr. Eng. Res. [Silsoe] 6(4): 252–258.

An automatic balance, designed for long-period unattended operation, is described. Intended primarily for weighing large soil containers (lysimeters) in the field, the compound lever system embodies beryllium-copper flexible pivots and a digital remote-reading output. Weight changes of as little as 1 pound can be continuously recorded in total loads of over 6 tons.—From auth. abstr.

Veihmeyer, F. J., and Hendrickson, A. H. 220

1955. Does transpiration decrease as the soil moisture decreases? Amer. Geophys. Union Trans. 36(3): 425–428, illus.

This paper gives results obtained from a prune tree and a pine tree grown in a suspended tank which permitted obtaining a continuous record of moisture loss from the soil. Additional results from field trials with pine, oak, and manzanita on a watershed area and from apricot and prune trees under cultivation show that the rate of moisture extraction from the soil is not influenced by the water in the soil so long as the latter is above the permanent wilting percentage.—Auth. abstr.

Visser, W. C. 221

1965. A method of determining evapotranspiration in soil monoliths. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 453–460.

In predicting the evapotranspiration of soils, the influence of soil properties needs a careful appraisal. From lysimeter experiments, for instance, there are indications that clay soils show lower evapotranspiration than sandy soils. The laws governing the influence of the soil on evaporation should be known if results of investigations obtained from particular soil profiles have to be transferred to some arbitrary practical case. The aim of the investigation should be to define as precisely as possible the complex of influences and to describe how the different properties contribute to the final value of evaporation. From definition of the action of the process of evaporation will follow what should be determined, whether direct or indirect, which kind of measurements should be made, and which level of accuracy of the determination is needed.

A model of the process of evaporation with respect to the influence of the soil is developed in this paper. The installation constructed to measure the required data is described.—From auth. introd.

Visser, W. C. 222

1959. The extension of the lysimeter technique into a field method for the determination of the water-balance. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 146–152.

Weaver, Robert J. 223

1941. Water usage of certain native grasses in prairies and pasture. Ecology 22(2): 175–192, illus.

Water losses by transpiration and surface soil evaporation were determined at Lincoln, Nebr., for seven species of prairie and pasture grasses in closely adjacent prairie and pasture habitats during their period of growth in 1939; a phytometer was used for each species (surface area, 1.77 square feet).

Trends of water losses were similar for all species, with a pronounced

maximum during mid-July when temperature reached 110° F. The phytometers with clipped vegetation lost 12 to 45 percent less than those with unclipped vegetation. Some evidence was obtained that losses from fully grown big bluestem were about 85 percent by transpiration and 15 percent by surface soil evaporation.—From auth. sum.

WILCOX, J. C. 224

1963. Effects of weather on evaporation from Bellani plates and evapotranspiration from lysimeters. Can. J. Plant Sci. [Ottawa] 43(1): 1–11.

Evaporation and evapotranspiration were measured in 1958 and 1959. Bellani plate evaporimeters proved to be just as reliable as class *A* pans and more convenient. Evapotranspiration was determined on alfalfa, ladino clover, and brome grass growing in lysimeters. Temperature, raidation, wind, and dewpoint were also determined. On a daily or weekly basis, temperature gave the highest correlations with evapotranspiration, but on a 2-hour basis, radiation gave the highest correlations. All four weather elements were found by partial correlation to have highly significant effects on both evaporation and evapotranspiration. Their effects on evaporation were quite similar to their effects on evapotranspiration. It is concluded that, if weather records are used to estimate evapotranspiration, all four of them should be used. Judging by the direct correlations, better estimates of evapotranspiration can be obtained by using evaporation records than by using any one weather record by itself.—From auth. abstr.

See also 139, 681.

Floating Lysimeters

ASLYNG, H. C. 225

1965. Evaporation, evapotranspiration and water balance investigations at Copenhagen, 1955–64. Acta Agr. Scand. [Stockholm] 15: 284–300.

During this study in Denmark the monthly evaporation from a water surface and the evapotranspiration from lysimeters were closely correlated.

The Penman formula overestimated the potential evapotranspiration the first half of the summer and of the year but was nearly in agreement with experimental data the latter half of the year.—From auth. sum.

ASLYNG, HANS C., AND KRISTENSEN, KNUD J. 226

1961. Water balance recorder. Amer. Soc. Civil Eng. Proc. J. Irrig. and Drainage Div. 87(IR 1): 15–21, illus.

This paper presents a detailed description of the design and construction of a semi-floating lysimeter. The installation consists of two tanks, one inside the other. The inner tank is partly floating and partly counterbalanced. Based on change in weight, the change in water level between tanks is amplified and recorded on a clock-driven chart. Results, based on the use of such a recorder, are presented.—Auth. synop.

BLACK, T. A., THURTELL, G. W., AND TANNER, C. B. 227

1968. Hydraulic load-cell lysimeters: construction, calibration, and tests. Soil Sci. Soc. Amer. Proc. 32(5): 623–629, illus.

The construction and calibration of two 35-metric-ton, hydraulic load-cell lysimeters with suction drainage systems are described. [These lysimeters were installed in the Sand Plains area of Wisconsin.] The butyl-nylon load cells contain an ethylene glycol-water mixture, and pressures are measured with a capacitative pressure transducer. Lysimeter sensitivity is 0.02 mm. evaporation. Daily evaporation from the lysimeter and the two independent micrometeorological methods agreed within 5 percent. On a June day, lysimeter measurements of evaporation from bare soil lagged measurements using the two other methods by almost 1.5 hours. Differences between the

lysimeter thermal regime and that in the surrounding soil accounted for the lag. By using foam plastic insulation of the tank walls, thermal regime differences were minimized.—Auth. abstr.

EKERN, PAUL C. 228

1965. Evapotranspiration of pineapple in Hawaii. Plant Physiol. 40(4): 736–739, illus.

The hydraulic-pillow system or floating lysimeter for weighing water changes in a soil tank was used to correlate evapotranspiration of pineapples to climatic factors. Bermudagrass was used for comparisons.

GLOVER, J., AND FORSGATE, J. A. 229

1962. Measurement of evapotranspiration from large tanks of soil. Nature [London] 195(4848): 1330.

A floating lysimeter was used to study evapotranspiration from perennial grass in Africa.

GLOVER, J., AND FORSGATE, J. A. 230

1964. Transpiration from short grass. Roy. Meteorol. Soc. Quart. J. [London] 90(385): 320–324, illus.

Transpiration from a low, closely matted perennial grass has been measured daily by a floating lysimeter, over a period which included a long natural drought. Transpiration was found to continue at a level determined by the physics of the environment until all the available moisture in the root range was exhausted. This supports Veihmeyer's hypothesis [Veihmeyer and Hendrickson 1957, 599] that available water is freely available to the plant between field capacity and wilting point.—Auth. abstr.

HANKS, R. J., AND SHAWCROFT, R. W. 231

1965. An economical lysimeter for evapotranspiration studies. Agron. J. 57(6): 634–636, illus.

The main feature of the floating lysimeter discussed in this paper is a tank placed on rubber bags, or pillows, filled with a liquid. Changes in soil-water content would be indicated by the pressure differences in the hydraulic system.

KING, K. M., MUKAMMAL, E. I., AND TURNER, V. 232

1965. Errors involved in using zinc chloride solution in floating lysimeters. Water Resour. Res. 1(2): 207–217, illus.

A differential transformer recording system, measuring changes in the level of the zinc chloride solution used to float sensitive lysimeters measuring evapotranspiration and dew, recorded errors arising from temperature changes in the solution. Since zinc chloride has certain advantages for use in floating the lysimeters, various methods were devised for compensating for these errors. Although complete correction was not obtained, the temperature errors were reduced to insignificant values with the use of a double float in a stilling well radially divided.—Auth. abstr.

KING, K. M., TANNER, C. B., AND SUOMI, V. E. 233

1956. A floating lysimeter and its evaporation recorder. Amer. Geophys. Union Trans. 37(6): 738–742.

This paper describes a weighing lysimeter in Wisconsin which operates on Archimedes principle and which has been used to obtain continuous values of evapotranspiration from an irrigated pasture. Some errors in evaluation of evapotranspiration by means of a lysimeter are discussed.—From auth. abstr.

MCMILLIAN, W. D., AND PAUL, H. A. 234

1961. Floating lysimeter. Agr. Eng. 42(9): 498–499, illus.

A floating lysimeter with a heavy liquid (zinc chloride) for buoyancy was found to be relatively inexpensive and reliable. Changes in soil-water storage are recorded to an accuracy of 0.008 inch of water depth.

POPOV, O. V. 235

1959. Lysimeters and hydraulic soil evaporimeters. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959, Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 49: 26–37.

ROSE, C. W., BYRNE, G. F., BEGG, J. E. 236

1966. An accurate hydraulic lysimeter with remote weight recording. Aust. C.S.I.R.O. Div. Land Res. Tech. Pap. [Melbourne] 27, 31 p., illus.

A review of existing weighing lysimeter installations indicated that none completely met the design specifications for an installation required in connection with integrated physical and plant-physiological studies at the Katherine (N.T.) Research Station (Division of Land Research, [Australia] Commonwealth Scientific and Industrial Research Organization). A new type of hydraulic lysimeter has been designed which possesses the features of high accuracy and rugged construction and where all measuring equipment is located in a safe and readily accessible position remote from the lysimeter. Details of the design, testing, and installation of this weighing lysimeter are given.—From auth. abstr.

See also 25, 626.

TENTS AND CHAMBERS

CAMPBELL, C. J. 237

1966. Periodic mowings suppress tamarisk growth, increase forage for browsing. U. S. Dep. Agr. Forest. Serv. Rocky Mt. Forest and Range Exp. Sta. Res. Note RM–76, 4 p., illus.

Tamarisk (*Tamarix pentandra* Pall.) was clipped (completely defoliated) and moved at 2-, 4-, 8-, and 24-week intervals throughout the growing season. Plant mortality increased with frequency of clipping. Plants were not killed by the 1 season of mowing, but dry foliage yields were similar to yields produced by clipping treatments. In central Arizona, mowings in May, July, and September are necessary to keep foliage succulent and within reach of browsing cattle. Evapotranspiration [determined by the evapotranspiration-tent method] decreased approximately 50 percent following mowing treatments.—Auth. abstr.

DECKER, JOHN P. 238

1960. A brief summary of the influence of phreatophytes on water yield in arid environments. *In* Symposium on Water Yield in Relation to Environment in the Southwestern United States, Sul Ross State Coll., Alpine, Tex., May 3, 1960. Southwest. and Rocky Mt. Div. of Amer. Ass. Advance. Sci. p. 64–69, illus.

After a brief summary of past research, the writer describes a new method for measuring evapotranspiration, based on an old technique: Confine a plant in a transparent vessel, ventilate at a known rate, measure absolute humidity of inflow and outflow, and multiply the humidity by the ventilation rate to compute the rate of water vapor production by the confined plant.

Field apparatus included frameless cylindrical tents (10 by 10 feet) of transparent plastic film sealed to the ground with sandbags and inflated by ventilating blowers. Small sample air streams were withdrawn continuously from a tent inlet and outlet and were directed alternately into the gas analyzer to determine evapotranspiration rates.

During July and August 1958, evapotranspiration measurements were

made on paired plots (one of closely grazed bermudagrass sod, the other of sod overtopped by one or more tamarisk shrubs) on the Salt River, 20 miles east of Tempe, Ariz. Evapotranspiration increased linearly with the amount of tamarisk. Though the plot with the most tamarisk was only about one-third fully stocked, its evapotranspiration rate was about four times that of the adjacent grass plot.

The apparatus is far from ideal for the following reasons: (1) The analyzer worked well on a laboratory bench but often became troublesome in the field; (2) no practical means was devised for calibrating the complete apparatus directly against known primary standards, and thus, calibration depended on secondary standards; and (3) the effect of enclosure has not been completely evaluated.—From auth. text.

DECKER, JOHN P., GAYLOR, WILLIAM G., AND COLE, FRANK D. 239
1962. Measuring transpiration of undisturbed tamarisk shrubs. Plant Physiol. 37(3): 393–397, illus.

The tent method of measuring evapotranspiration from undisturbed plots of natural vegetation was used to compare the evapotranspiration rates of five-stamen tamarisk and bermudagrass. Evapotranspiration of bermudagrass-tamarisk plots increased linearly with the amount of tamarisk. A reduction of evapotranspiration could thus be expected to follow conversion of tamarisk stands to grass cover. The diurnal time-course of evapotranspiration followed generally the changes of light intensity and humidity deficit. On clear days evapotranspiration for a midday period (10:00 AM–2:30 PM) and for the night (8:30 PM-5:30 AM) was 36 percent and 11 percent, respectively, of the daily total.—From auth. sum.

DECKER, J. P., AND SKAU, C. M. 240
1964. Simultaneous studies of transpiration rate and sap velocity in trees. Plant Physiol. 39(2): 213–215.

Sap velocity, as measured with a heat-pulse meter, and actual transpiration rate, measured directly as vapor production rate, were found to be closely correlated for intact trees.—Auth. sum.

DECKER, JOHN P., AND WETZEL, BARTON F. 241
1957. A method for measuring transpiration of intact plants under controlled light, humidity, and temperature. Forest Sci. 3(4): 350–354, illus.

A laboratory method has been developed for measuring transpiration of potted plants under controlled light, humidity, and temperature. An infrared gas analyzer (Liston-Becker model 15*A*) serves as a sensitive and fast-acting hygrometer. This method was tested on potted seedlings of five-stamen tamarisk and Arizona cypress. Transpiration rate increased as light intensity and temperature increased; rate decreased with rising humidity. Work is under way to adapt this method to field use.—Auth. sum.

DECKER, JOHN P., AND WIEN, JANET D. 242
1960. Transpirational surges in *Tamarix* and *Eucalyptus* as measured with an infrared gas analyzer. Plant Physiol. 35(3): 340–343.

An intact twig of tamarisk or leaf of eucalyptus was sealed in an illuminated, constant-temperature glass chamber that was ventilated at a known rate with dry air. Absolute humidity of air flowing from the chamber was recorded continuously by an infrared gas analyzer. Humidity multiplied by ventilation rate gave transpiration rate. Transpiration increased smoothly to a new constant rate during illumination and decreased smoothly upon darkening. When a twig or petiole was severed in air, transpiration accelerated briefly in a smooth surge and then declined. Behavior was variable when the cut was made under water, but transpiration usually slowed to a new constant rate, then surged briefly when the cut was exposed to air.—Auth. sum.

GRIEVE, B. J., AND WENT, F. W. 243

1965. An electric hygrometer apparatus for measuring water-vapor loss from plants in the field. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 247–257.

In studies on the physiological diversity of water economy in plants in the field, a prime need is for a rapid yet sensitive method which can be applied to intact plants. The torsion balance rapid-weighing technique which has been most frequently used in eco-physiology has the basic disadvantage that each leaf has to be cut off before its rate of water loss is determined. The sensing hygrometer apparatus described in this article makes possible the instantaneous determination of water-vapor loss from leaves left intact on the plant. The speed of use allows numerous observations to be made on selected leaves in the course of a day. A better estimation of the overall daily march of water-vapor loss is thus possible.—From auth. introd.

LEE, RICHARD 244

1966. Effect of tent type enclosures on the microclimate and vaporization of plant cover. Oecol. Planatarum [Paris] 1: 301–326.

Inflatable plastic enclosures used to sample vaporization rates alter the microclimate of the space enclosed. The radiation greenhouse effect is relatively less important than reduced ventilation in raising the daytime equilibrium energy level. In the arid Southwest, daytime enclosure effects in summer usually result in a greater water stress as indicated by the (1) sap flow index, (2) dendrograph, (3) vapor pressure difference between leaves and air, and (4) evaporation and transpiration of atmometers and potted plants. Differential enclosure effects of cover types, determined in part by the strata that they occupy in the tent, make the technique of doubtful value in the estimation of relative water loss.—Auth sum.

MACE, ARNETT C., JR. 245

1968. The influence of climatic, hydrologic, and soil factors on evapotranspiration rates of tamarisk (*Tamarix pentandra* Pall.) Diss. Abstr. 28(9): 3548 B.

In the arid Southwestern United States, where water is a limiting factor in agricultural and industrial development, a sizable portion of the annual precipitation may be lost through evapotranspiration. In Arizona such losses account for approximately 95 percent of the annual precipitation.

Tamarisk (*Tamarix pentandra* Pall.) is estimated to occupy over one million acres of the flood plains and streambanks in the Southwest. Although it is reported to use a large quantity of water, accurate estimates of evapotranspiration are unknown. Evapotranspiration processes are complex and depend on many interrelationships of the soil-plant-atmosphere system. Although water use by tamarisk has been intensively studied, evapotranspiration measurements under different climatic and hydrologic conditions are not available.

The evapotranspiration tent was selected to measure evapotranspiration rates of tamarisk under varying climatic and hydrologic conditions. Modifications of the tent reduced serious enclosure effects of the original tent. Evapotranspiration rates measured by the revised tent agreed favorably with rates computed by Penman's equation.

An intensive laboratory study was conducted to determine the effect of salinity on transpiration rates of tamarisk at different vapor pressure deficits. Results indicated that the effect of salinity is dependent on vapor-pressure deficit. Transpiration rates were linearly related to vapor-pressure deficits at low salinity levels, but a curvilinear relationship was obtained at high salinity levels.

MACE, ARNETT C., JR., AND THOMPSON, J. R. 246

1969. Modifications and evaluations of the evapotranspiration tent. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Res. Pap. RM-50, 16 p., illus.

Reduced ventilation rate is the principal cause of heat buildup inside the original plastic evapotranspiration tent. After the tent was modified to increase wind movement, data indicated no significant increase in air temperature within the enclosure as long as it was fully occupied by vegetation. Future modification should include a variable tent size and improved airflow measurements.—Auth abstr.

MINCKLER, LEON S. 247

1936. A new method of measuring transpiration. J. Forest. 34(1): 36–39, illus.

This paper reports on a method devised by the writer which makes it both possible and practical to calculate the transpiration of full-sized trees growing in the forest. Air is drawn over leaves enclosed in a glass chamber 18 inches high and 8 inches in diameter and thru U-tubes where the water vapor is absorbed. Two new drying agents, "anhydrone" (Anhydrous magnesium perchlorate) and "desicchlora" (anhydrous barium perchlorate), proved to be excellent.

SEBENIK, PAUL G., AND THAMES, JOHN L. 248

1967. Water consumption by phreatophytes. Progr. Agr. in Ariz. 19(2): 10–11, illus.

This report summarizes a study conducted on the San Pedro River flood plain in Arizona, on transpiration by tamarisk shrubs during the summer of 1966. Measurements were made by a modified evapotranspiration tent (Mace and Thompson 1969, 246). Evapotranspiration as measured with the tent exceeded pan evaporation data recorded at several sites in southern Arizona.

At the study site there were 895 shrubs per acre. The average monthly loss of water was computed at 1.1 acre-feet from July to September. It is concluded that it is not possible to predict the actual amount of water that could be saved each year by clearing the bottom lands, since the rate of water use from the area after clearing would depend on subsequent treatment of the area.

SLATYER, R. O., AND BIERHUIZEN, J. F. 249

1964. A differential psychrometer for continuous measurement of transpiration. Plant Physiol. 39(6): 1051–1056, illus.

The instrument described in this paper provides a simple yet accurate means of continuously measuring transpiration of plants or parts of plants in enclosures.

STARK, N. 250

1967. The transpirometer for measuring the transpiration of desert plants. J. Hydrol. [Amsterdam] 5(2): 143–157, illus.

This paper compares transpiration results obtained through use of the electronic hygrometer and quick-weighing methods. It was determined that quick-weighing results from several species compared closely in direction with hygrometer data. The paper describes the water loss from greasewood (*Sarcobatus vermiculatus*) branches differing in condition and from separate clumps of saltgrass (*Distichlis stricta*). The dark-green leaves of greasewood appear to be better able to control water loss than the yellow-green leaves. The study followed the curves for water loss during flowering and fruiting of sagebrush (*Artemisia tridentata*) and rabbitbrush (*Chrysothamnus nauseosus albicaulis*), using the same 10 branches for study over a 2-month period. Both of these species appear to be able to control water

loss during the period of fruit expansion somewhat independently of air temperatures and relative humidity. Water loss is rapid in rabbitbrush as the fruit accessory tissues dry out.—From auth. abstr.

TOMANEK, G. W., AND ZIEGLER, R. L. 251

1962. Ecological studies of saltcedar. Fort Hays Kansas State College, Div. of Biol. Sci. Fort Hayes, Kans. 128 p., illus.

Though this paper primarily covers the ecology of the saltcedar (*Tamarix pentandra*), a section is devoted to transpiration studies conducted in greenhouse and field. The gravimetric method was used for the greenhouse studies, with the plants sealed in polyethylene plastic over glazed crocks. Tests were run for about 2 months; saltcedar, cottonwood, and willow were used. A comparison demonstrated an average total water loss for the period of 5,775 gm. for saltcedar, 5,047 gm. for willow, and 2,791 gm. for cottonwood. The plants were similar in size, but saltcedar had a much greater leaf surface per plant. The average daily water loss from the study plants per square dm. of leaf surface was 3.80 gm. for saltcedar, 5.55 gm. for cottonwood, and 8.23 gm. for willow.

For field studies, an apparatus was used in which a stream of air was passed through a plastic chamber containing a plant or a portion of a plant. The airstream then passed out of the chamber through glass tubes which contained calcium chloride, a water-absorbing agent. A second identical apparatus was used without a plant to determine the portion of water vapor which came from the atmosphere. This method was compared with the gravimetric method used in the greenhouse test and found to yield comparable results.

Results from the field tests showed a large (5 ft. tall) saltcedar transpired 27.6 gm. per hour as compared with 20.4 gm. for a 5-ft. willow, 14.9 gm. for a 3.5-ft. cottonwood, and 16.1 gm. for a small saltcedar. When related to the leaf surface, the square dm. loss per hour was 0.050 gm. for the large saltcedar and 0.129 for the small saltcedar as compared to 0.080 for the willow and 0.052 for the cottonwood. Thus, the small saltcedar had the greatest evapotranspiration rate per leaf area and the large saltcedar had the least.

See also 262-264, 433, 684.

SOIL MOISTURE, RUNOFF, AND OTHER PLOT STUDIES IN WILD-LAND AREAS

Arid Climates

BAUER, HARRY L. 252

1936. Moisture relations in the chaparral of the Santa Monica Mountains, California. Ecol. Monogr. 6(3): 409–454, illus.

During the two years 1931–32 and 1932–33, an intensive instrumental investigation was made of the vegetation, chiefly chaparral, and the physical conditions, especially soil moisture and evaporation, of a representative area of the Santa Monica Mountains, Calif.

BLANEY, HARRY F., AND TAYLOR, C. A. 253

1930. Rainfall penetration and consumptive use of water on valley floors. *In* Rainfall Penetration and Consumptive Use of Water in Santa Ana River Valley and Coastal Plain. Calif. Dep. Public Works Div. Water Resour. Bull. 33: 19–104, illus.

Rainfall penetration was determined by taking soil-moisture samples to a depth below the root zone. Rainfall penetration stations were established on the predominant soil types and studies were made of rainfall, runoff, transpiration, evaporation, and depths of penetration.

Seasonal precipitation of at least 19 inches is necessary before any ma-

terial amount of water will penetrate below the brush root zone of the Santa Ana River Valley floors. If the soil supports a dense grass and weed cover, the consumptive use of water indicated is 12 to 15 inches before deep penetration takes place.

DeByle, Norbert V., Johnston, Robert S., Tew, Ronald K., and Doty, Robert D. 254

1969. Soil moisture depletion and estimated evapotranspiration on Utah watersheds. Int. Conf. on Arid Lands in a Changing World, Univ. of Ariz., Tucson, Ariz., June 3–13, 1969, 14 p., illus. Processed.

Evapotranspiration is the principal component of the hydrologic cycle that can be modified by watershed managers. In the Western United States, measured soil moisture depletion plus summer precipitation gives a good estimate of actual evapotranspiration. Fourteen sites representing 10 vegetative types typical of Utah's water-yielding lands were studied. Soil-moisture depletion during the growing season, measured with the neutron-scatter technique, varied from 0.88 inch under a young stand of aspen sprouts to 20.38 inches under a mature aspen stand. Losses from grass, Gambel oak, sagebrush, snowberry, Douglas-fir, and bare soil were intermediate. The resulting inventory of water use by native plant communities, at elevations of 6,100 feet to 9,200 feet, provides a basis for further water-yield improvement research, especially for measuring effects of converting or modifying vegetation on watersheds in arid regions.—From Selec. Water Resour. Abstr. 2(18): 3

Hendrickson, A. H. 255

1942. Determination of the losses of moisture by evaporation from soils in a watershed area. Amer. Geophys. Union Trans. 23(2): 471–477.

Based upon success of measurements in orchards, it can be concluded that soil-moisture records could give reliable data on water losses from watersheds. Use of soil-moisture constants, such as moisture equivalent and wilting percentage, in the determination of water losses is fully discussed.

Rowe, P. B. 256

1941. Some factors of the hydrology of the Sierra Nevada foothills. Amer. Geophys. Union Trans. 22(1): 90–100, illus.

The purpose of this paper is to discuss briefly some factors of the hydrology of the Sierra Nevada foothills of the San Joaquin Basin, Calif. The data presented are primarily concerned with the hydrologic phases of a study started by the U.S. Forest Service at North Fork, Calif., in 1929 to determine the influence of the woodland-chaparral vegetation on water yield, surface runoff, and erosion.—From auth. sum.

Rowe, P. B. 257

1958. Tests of applied watershed management to increase water yield, San Dimas Experimental Forest. *In* Preliminary Economic Consideration of the Arizona Watershed Program. Ariz. Watershed Symp. Second Annu. Proc., Phoenix, Ariz., Sept. 22, 1958. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 59–62, illus.

This paper reports on studies conducted at the San Dimas Experimental Forest, in California, concerning watershed management. For several years rainfall, soil, and water relations on nine hillside plots heavily covered with native brush, mostly scrub oak, were recorded and compared. Then in the winter of 1951–52, the brush from six of the plots was cleared and a mixed cover of annual grasses was established. After 3 years of maintaining the grass plots with herbicide spraying, the spraying was discontinued. Natural

brush cover on the remaining three plots was undisturbed during this period. During the fourth year, a heavy growth of forbs developed on the six grass plots.

Results from this study indicate that, in the mountains of southern California, considerable water can be saved by converting brush to grass in areas of deep soils, but in areas of low rainfall or in areas of shallow soils little or no water can be saved.

The paper describes two other studies of vegetation treatment that were initiated in 1958: Riparian clearing in Monroe Canyon and deep-soil chaparral conversion in Bell Canyon.

ROWE, P. B., AND COLMAN, E. A. 258

1951. Disposition of rainfall in two mountain areas of California. U.S. Dep. Agr. Tech. Bull. 1048, 84 p., illus.

This bulletin reports two studies seeking to evaluate and explain some of the hydrologic processes involved in the disposition of rainfall in two mountain areas: One in the Sierra Nevada of central California, the other in the San Gabriel Mountains of southern California. Study of rainfall disposition is basic to an understanding of the role of soil and vegetation in watershed management.

The research had two parts: First, determination of water losses and water yield under natural (undisturbed) vegetation and study of how annual burning and denudation affect losses and yield; and second, calculation of the water losses and yield of a watershed.

The first part was conducted on hillside plots. Interception loss and surface runoff were measured, and periodic measurements of soil moisture used to calculate evapotranspiration losses. Percolation (the water yielded by percolating through the soil mass) was calculated as the difference between rainfall and the sum of surface runoff and the evaporative water losses. Some of the plots were left covered with natural vegetation, some were burned annually, and some were trenched to exclude roots and maintained bare of vegetation.

In the second part, 14 moisture-sampling plots within an 875-acre watershed were studied under natural vegetation. The water yield of the watershed was calculated from the plot results and streamflow measurements.—From auth. introd.

ROWE, P. B., AND REIMANN, L. F. 259

1961. Water use by brush, grass, and grass-forb vegetation. J. Forest. 59(3): 175–180.

A plot study on the San Dimas Experimental Forest, in the San Gabriel Mountains of southern California, indicated wide differences in seasonal and annual evapotranspiration from deep soil beneath grass and brush covers. Evaluations and comparisons were made during years of high (40.5 inches), moderate (24.9 inches) and low (15.5 inches) rainfall. One set of plots was left in its natural vegetation of dense oak-brush cover. The other set was cleared of brush and sown to Italian ryegrass (*Lolium multiflorum*). The grass cover was maintained for 2 years by killing all brush sprouts with 2,4,5-T. The fourth year a heavy stand of summer-growing forbs was allowed to develop. In the years without weed growth, evapotranspiration was 15.5 inches (evapotranspiration with brush was 23.4 inches). In the fourth year the grass-forb evapotranspiration was 17.0 inches; the evapotranspiration from brush was 18.0 inches. The results indicated that the brush plots transpired 8 inches more than the grass plots during the years of high and moderate rainfall. In a year of low rainfall, the transpiration of the brush plot was only 3 inches more than that of the grass.

SHACHORI, A. Y. 260

1965. Forest hydrology research in Israel. *In* International Symposium

on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29-Sept. 10, 1965. Pergamon Press, N. Y. p. 53–57.

This paper is a brief outline of current forest and range hydrology research and related studies in Israel. The survey is divided into three categories: Studies of individual plants or species, studies of whole vegetative complexes, and studies of complete watersheds.

SHACHORI, A. Y., AND MICHAELI, A. 261

1965. Water yields of forest, *maquis* and grass covers in semi-arid regions: a literature review. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 467–477, illus.

Depletion of ground water accompanied by an increase in evergreen vegetation, both forested and chaparral, concentrated attention on the probable effect of increased water consumption by this type of vegetation cover and, as a result, decreased recharging of ground water. It has been claimed that the evergreen vegetation, through its deep root system, utilizes moisture throughout the summer and during dry winter periods from water in soil washed into cracks in rocks or from water temporarily stored above relatively impervious lenses; the water thus used is then not available for recharging ground water. On the other hand, it has been suggested that with annual and grassy vegetation this phenomenon is confined to the shallow soil horizons above the rock because of the shallow root system of this type of vegetation. Because of the practical importance of this problem, plans were made for a comprehensive research program on it in Israel.

In view of worldwide interest in this problem, a study was made of available information on the subject. This article contains the abbreviated results of the study.

SHACHORI, A., ROSENZWEIG, D., AND POLJAKOFF-MAYBER, A. 262

1965. Effect of Mediterranean vegetation on the moisture regime. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29-Sept. 10, 1965. Pergamon Press, N. Y. p. 291–311, illus.

Moisture withdrawal by various types of vegetation was studied in the Carmel Mountains in Israel; the neutron scattering method was used. Moisture withdrawal was determined to a depth of 30 feet. It was found that deep-rooted species of maqui shrubs and pine consume considerable quantities of moisture from the soil and rock complex. This moisture is taken from deeper layers throughout late spring and summer. The maqui shrub can utilize moisture from depths down to 24 feet. Pine utilizes similar, but somewhat lesser, quantities at a shallower depth. Pasture cover, mainly grasses, utilizes the upper layers, down to rock, but very little usage below 6 to 9 feet was indicated.

There was little difference in the moisture depletion of the various cover types in the upper 3 feet. The average annual moisture withdrawal by the vegetative types studied was found to be: Maqui, 452 mm.; pine, 410 mm.; pasture, 327 mm.; and bare soil, 265 mm. The average difference in moisture withdrawal between maqui shrub and pasture was about 125 mm. However, differences vary according to prevailing precipitation conditions.

There was no ground-water recharge in years of low rainfall under maqui and pine covers, while pasture contributed 75 mm. and bare soil, 85 mm. to ground water. In a year of average rainfall of about 700 mm., maqui shrub contributed 230 mm.; pine, 347 mm.; and pasture, 420 mm. to ground-water recharge. Although it was generally impossible to separate winter evapotranspiration values from deep percolation with the neutron scattering technique, it was possible to estimate this value directly in the maqui plot, in

a dry year, as 125 mm. Another technique should be applied to yield information on winter evapotranspiration, such as the energy-balance or transpiration-tent technique, in order to provide an independent check on the values obtained in this study.—From auth. abstr.

SHACHORI, A. Y., STANHILL, G., AND MICHAELI, A. 263

1965. The application of integrated research approach to the study of effects of different cover types on rainfall disposition in Carmel Mountains, Israel. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 479–487, illus.

This paper reports on an approach used in Israel to determine evapotranspiration and deep percolation. The approach integrates three techniques on the assumption that no one of the techniques would be adequate in determining either evapotranspiration or deep percolation throughout the hydrological year. The combination of the three techniques applied simultaneously to an area provides a check on the operation of each one of the techniques.

The techniques are: (1) Measurement of moisture changes of soil and rock within the range of root growth; (2) direct measurement *in situ* of evapotranspiration from the vegetation, through use of a plastic tent; and (3) radiation balance determination, from a helicopter of the net energy available for transpiration.

ROSENZWEIG, D. 264

1969. Study of difference in effects of forest and other vegetative covers on water yield. Fourth Annu. Rep. March 1968-March 1969, Soil Erosion Res. Sta., Ruppin Inst. Agr., Emek-Hefer, Israel, Rep. 8, 39 p., illus. Processed.

This report summarizes to date the results of the evapotranspiration study in the Carmel Mountains of Israel. The main effort in 1968 was focused on improving the evapotranspiration tent used in the project. The improved model of the tent appears to be a satisfactory method for measuring evapotranspiration *in situ*. As a direct means of measuring evapotranspiration, it can usefully replace many indirect methods. It has a clear advantage over the neutron meter when problems of high water table or continued deep percolation are encountered. Also, it circumvents problems of topography, surface roughness, and border effects that limit the usefulness of the energy balance method in many instances. The report includes the 1968 measurements of soil moisture and the results of the radiation studies. Deep percolation of moisture into the soft rock formation was determined this year for the first time. This makes possible a more accurate calculation of evapotranspiration from the pine cover.

VEIHMEYER, F. J. 265

1953. Use of water by native vegetation versus grasses and forbs on watersheds. Amer. Geophys. Union Trans. 34(2): 201–212, illus.

Soil-moisture records for several years were obtained for plots on potential range lands in California on which native vegetation (mostly woody brush species) was left intact and from adjacent plots which were denuded by burning. Samplings, by which the amounts of soil moisture could be measured quantitatively, were taken with soil tubes, generally under extremely difficult conditions, frequently enough to give a satisfactory picture of the water regimen of the area.

More than 23 paired plots were used in the experiments. They were selected to give a wide variety of vegetative types, rainfall patterns, topography, and soils. At all of the sites the rain generally fell from October through March; most of it fell in December, January, and February. The growth of the plants, therefore, was dependent to a large extent upon the

amount of water that could be stored in the soil mantle. Following the fire, grasses and forbs usually succeeded the brush, but with some species, several annual burnings were necessary before the brush was eliminated. The removal of the brush resulted in a saving of moisture.

The moisture content of the soil was higher in the burned plots than in the unburned plots at the end of the growing season; consequently, less water was required to restore the soil in the burned plots to its field capacity. In most cases the results led to the conclusion that appreciable savings of water could be effected by burning woody brush to substitute grasses or forbs which have forage value. The soil-moisture records show that the soil in the burned areas was wet to its field capacity as early as, and in many cases earlier than, in the unburned ones, thus indicating that the permeability of the soil for water was not adversely affected by burning.—From auth. abstr.

VEIHMEYER, F. J., AND JOHNSTON, C. N. 266
1944. Soil-moisture records from burned and unburned plots in certain grazing areas of California. Amer. Geophys. Union Trans. 25(1): 72–84, illus.

After plots are burned, the extraction of moisture from the soil seems to depend upon the ability of the species of plants which grow after burning to extend their roots throughout the full depth of the soil and upon the persistency of the plants throughout the growing season. In every case in unburned plots, the moisture content of all of the soil was reduced to the permanent wilting percentage. On the other hand, on those plots where brush did not sprout and where grasses grew for a short time early in the season, the soil moisture, except in the surface layer, was not reduced to the permanent wilting percentage. Under such conditions burning will result in the saving of water and, at the same time, in the production of forage.

The records indicate that runoff and erosion were not accelerated on the burned plots in the areas where these experiments were conducted.—From auth. sum.

See also 53, 290, 365, 366, 677, 684.

Forest Climates

ANDERSON, HENRY W., AND GLEASON, CLARK H. 267
1960. Effects of logging and brush removal on snow water runoff. *In* General Assembly of Helsinki, July 25-Aug. 6, 1960. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 51: 478–489.

Water yield as affected by three types of logging in a red fir forest, by two kinds of slash disposal, and by brush removal is being studied in the snow zone of the Cascade Range and the Sierra Nevada in California.

It is concluded that water yield from snow zone runoff can be influenced in both amount and time of delivery by the manner in which areas are logged and by brush removal.—From auth. sum.

BROWN, H. E., AND THOMPSON, J. R. 268
1965. Summer water use by aspen, spruce and grassland in western Colorado. J. Forest. 63(10): 756–760.

Soil moisture was measured in spring and fall of 1955, 1957, and 1958 to determine relative amounts of water use on sites occupied by quaking aspen, Engelmann spruce, and mountain grassland during the summer growing season. Study plots were located on sites where the soil was deep enough to permit gravimetric sampling to a depth of 8 feet. Water use was considered as the difference between soil moisture in the spring and fall, adjusted for summer precipitation. Aspen plots averaged 19.2 inches, spruce 14.9 inches, and grassland 8.9 inches of water use yearly for the 3 years of record.

Because the amount of spring soil moisture was significantly different among types, however, and because spring moisture was correlated with water use in aspen and spruce types, it was impossible to attribute differences in water use solely to the type of vegetation.—Auth. abstr.

CROFT, A. R., AND MONNINGER, L. V. 269

1953. Evaporation and other water losses on some aspen forest types in relation to water available for stream flow. Amer. Geophys. Union Trans. 34(4): 563–574, illus.

This paper reports the effects of altering an aspen forest cover in Utah on evapotranspiration losses, overland flow, erosion, and mantle storage deficits during 3 successive growing seasons. These data, together with supplemental measures of winter precipitation and estimates of evaporation from snow, provided a basis for estimating amounts of water available for streamflow. Removal of aspen trees, leaving the herbaceous understory and litter undisturbed, reduced evapotranspiration losses and increased the amount of water available for streamflow by about 4 inches without seriously increasing overland flow or soil erosion during summer rains. Removal of the remaining herbaceous cover further reduced evapotranspiration losses and increased the amount of water available to streams by an additional 4 inches but resulted in an undesirable increase in summer rainfall runoff and soil loss.—Auth. abstr.

DUNFORD, E. G., AND NIEDERHOF, C. H. 270

1944. Influence of aspen, young lodgepole pine, and open grassland types upon factors affecting water yield. J. Forest. 42(9): 673–677.

Burned and cutover lands in the Rocky Mountains present a distinct problem in watershed management. Many of these areas support a cover of grass or aspen rather than their original stand of lodgepole pine or spruce. Generally the new cover provides adequate protection from erosion, but its other watershed qualities have been questioned. In order to evaluate some of these qualities, this preliminary study was undertaken in Colorado. The results indicate that, from the standpoint of water available for streamflow, aspen and grass are probably superior to a dense coniferous forest.—From auth. abstr.

GOODELL, B. C. 271

1952. Watershed management aspects of thinned young lodgepole pine stands. J. Forest. 50(5): 374–378, illus.

This study demonstrated that the thinning of dense forest stands will appreciably increase the net precipitation received on the forest floor. In the Fraser Experimental Forest, in Colorado, thinning of lodgepole pine in one area increased the amount of snow reaching the ground by 20 percent and increased the amount of summer rainfall reaching the ground by 15.5 percent. Data indicate that evaporation and transpiration losses of the soil moisture were unaffected by the thinning treatments.—From auth. sum.

RUTTER, A. J. 272

1965. An analysis of evaporation from a stand of Scots pine. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29-Sept. 10, 1965. Pergamon Press, N. Y. p. 403–417, illus.

Evaporation from a forest of *Pinus sylvestris* in southeast England was estimated from two sets of observations. The first consisted of direct determinations of interception, transpiration, and evaporation from the soil surface in 44 sample 24-hour periods during 3 years; the second, of observations on changes in soil moisture when the soil was drier than field capacity during 6 years. Resistances to vapor diffusion and transport were determined,

namely, the internal resistance of the leaf in relation to stomatal behavior and the resistance between the leaf and the air above the canopy in relation to wind speed. These resistances, suitably transformed, were incorporated in Penman's formula, which was then found to give a satisfactory fit with observed evaporation. The rate of evaporation of intercepted water was many times as great as the transpiration rate in similar conditions, and the theoretical treatment accounted for this. The significance of interception in total evaporation from this forest is briefly discussed.—From auth. abstr.

WILM, H. G., AND DUNFORD, E. G. 273
1948. Effect of timber cutting on water available for streamflow from a lodgepole pine forest. U. S. Dep. Agr. Tech. Bull. 968, 43 p., illus.

Timber cutting exerted pronounced effects on all the measured components except soil moisture, and these effects increased consistently with the intensity of timber removal. On the average, for example, the initial storage of snow was increased 26 percent by the heaviest timber cutting and 5 percent by timber stand improvement.—From auth. sum.

WATERSHED STUDIES

General Discussion

BLACK, PETER E. 274
1963. Timber and water resource management. Forest Sci. 9(2): 137–145, illus.

This paper presents an economic analysis of the physical relationship between the production of timber and water on wild lands. Recent studies have indicated that water yield may be increased through certain types of forest cutting under certain conditions; though this relationship is not fully known, economic research into potential management of these two resources is needed. Based on research at the U.S. Forest Service's Fraser Experimental Forest, in Colorado, a graphical and mathematical procedure for predicting stream yield increases due to forest cutting is developed. Inventory data on streamflow and timber stands on the headwaters of the Fraser River, which supplies water to Denver, Colo., via the Moffat Tunnel, were used in the analysis. It is concluded that the management intensity indicated by the analysis for the watershed is both realistic and desirable and that the use of minimum figures throughout the analysis enhances its practical value in application to the land through good land management practices.—From auth. abstr.

HEWLETT, JOHN D., LULL, HOWARD W., AND REINHART, KENNETH G. 275
1969. In defense of experimental watersheds. Water Resour. Res. 5(1): 306–216.

Recent criticisms discount the contribution of experimental watersheds to the science of hydrology and to watershed management. The critics cite as disadvantages the cost of experimental watersheds, their unrepresentativeness, leakiness, difficulty in applying results to other areas, and the lack of progress in basic knowledge about hydrologic processes. Some critics propose mathematical synthesis, statistical analysis, plot studies, soil moisture studies, meteorological methods, and the study of individual hydrologic processes as alternatives to experimental watersheds. The criticisms lack weight because published results of catchment experiments were not carefully reviewed. The alternatives are obviously aids rather than substitutes for experiments on watersheds. By reference to recent and older results, the authors argue that the experimental watershed method has produced much of our present knowledge about the land phase of the hydrologic cycle and man's influence on it, that the method is sound, and that its future in any comprehensive research program is secure.—Auth. abstr.

HIBBERT, ALDEN R. 276

1965. Forest treatment effects on water yield. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 527–543, illus.

Results are reported for 39 studies of the effects of altering forest cover on water yield. Taken collectively, these studies reveal that forest reduction increases water yield and that reforestation decreases water yield. Results of individual treatments vary widely and, for the most part, are unpredictable. First-year response to complete forest reduction varies from 34 mm. to more than 450 mm. of increased streamflow. A practical upper limit of yield increase appears to be about 4.5 mm. per year for each percent reduction in forest cover, but most treatments produce less than half this amount.

There is strong evidence that in well-watered regions, at least, streamflow response is proportional to reduction in forest cover. As the forest regrows following treatment, increases in streamflow decline; the rate of decline varies between catchments but appears to be related to the rate of forest recovery. Seasonal distribution of streamflow response to treatment is variable; response in streamflow may be almost immediate or considerably delayed, depending on climate, soils, topography, and other factors.—From auth. abstr.

ROTHACHER, JACK 277

1965. Experimental watersheds used as a research tool by the Forest Service. Unit Source Watershed Conf. Notes, Feb. 16–19, 1965. U. S. Dep. Agr., Agr. Res. Serv., Soil and Water Conserv. 16 p., illus. (Reprinted by the Forest Serv., U. S. Dep. of Agr.)

Experimental watersheds are the traditional approach to the study of the effect of land treatment on streamflow and sedimentation. In spite of emphasis on more basic research and the use of modern research technique, watersheds still play an important part in the U. S. Forest Service's watershed management research program.

A list of over 250 gaged watersheds is included in this publication, along with a discussion of important results. Many of these watersheds are in mountainous headwater streams where forests remain the dominant vegetation. The importance of these lands for the production of water is recognized. It is no longer claimed that forests produce water, but it is realized that forests are there because of the climatic factors—including higher precipitation. How we manage the forests and associated range and alpine areas has an important effect on the characteristics of streamflow and quality of water produced.

Although specific objectives of Forest Service watershed studies cover a wide range, they will relate in some measure to the effect of various forest management practices on yield, distribution, or quality of water produced. In some areas emphasis is on total yield, almost without regard for timing or quality; in other areas, flood flows and sedimentation may be most important; in still others, minimum flows of the year are of most concern or, perhaps, only quality is of prime importance. On a portion of the experimental watersheds, snow plays a major part in the hydrologic regime.

Since forest lands must be managed for products other than water, the general objective of Forest Service watershed management research is to discover how to maintain an adequate flow of good quality water yet utilize the land for economic output of timber, for grazing, and for recreation.—

See also 50, 327, 328 458, 653, 660.

BAILEY, R. W., AND COPELAND, OTIS L., JR. 278

1960. Low flow discharges and plant cover relations on 2 mountain watersheds in Utah. *In* General Assembly of Helsinki, July 25–Aug. 6, 1960. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 51: 267–278.

Twenty-two years of streamflow records provide a basis for comparing the behavior of low flow discharges from two adjacent mountain watersheds of contrasting use history in northern Utah.—From auth. abstr.

BATES, C. G., AND HENRY, A. J. 279

1928. Forest and stream-flow experiment at Wagon Wheel Gap, Colorado. Mon. Weather Rev., Suppl. No. 30, 79 p., illus.

The experiment discussed in this paper was conducted from 1910 to 1926 and dealt with streamflow from two mountain watersheds of about 200 acres each, located on the drainage of the Rio Grande in southern Colorado. Their elevations are between 9,000 and 11,000 feet. The forest cover was Douglas-fir, Engelmann spruce, and aspen.

The flood runoff of watershed *B* before denudation was the same as that of *A;* after denudation of *B,* the spring flood on that watershed increased to a peak discharge in the third year after denudation of about 35 percent excess and then diminished until the end of the experiment, when it was 22 percent greater than that of *A*.

In the predenudation years the average annual precipitation was 21.03 inches; the average runoff of *A* was 6.08 inches and that of *B* was 6.18 inches. In the postdenudation period the average precipitation was 21.16 inches; the flow of *A* was 6.20 inches and that of *B* was 7.26 inches. These figures indicate an excess flow from *B* of about 0.96 inch for the average of seven postdenudation years.—From auth. sum.

BISWELL, H. H., AND SCHULTZ, A. M. 280

1958. Effects of vegetation removal on spring flow. Calif. Fish and Game 44(3): 211–230, illus.

Quantitative measurements were made on the effects of brush removal and manipulation on spring and creek flow. In some cases, the brush and trees were top-killed by control burning and the areas converted to grassland; in others, the woody plants around springs were cut out with an ax. Increases in flow resulted from these operations, in most cases almost immediately.

Three principles govern spring and streamflow changes resulting from plant-cover manipulations: (1) Conversion from deep-rooted trees and shrubs to shallow-rooted grass makes the water in the deeper zones (below the grass roots) available for spring flow, (2) removal of transpiring surface of plants whose roots are in free water results in immediate increases in spring and streamflow, and (3) practices which decrease the infiltration capacity of the soil, resulting in high surface runoff, may retard spring flow or stop it altogether.—From auth. sum.

BROWN, HARRY E. 281

1971. Evaluating watershed management alternatives. Amer. Soc. Civil Eng., J. Irrig. and Drainage Div. 97 (IR1): 93–108, illus.

On the Beaver Creek [Arizona] Pilot Project multiple use evaluations are being made of watershed management treatments designed to increase water yield. So far there have been modest gains in cattle forage following cabling Utah juniper and felling alligator juniper, but these are offset by complete loss of wood production. Water and sediment yields are unchanged, and wildlife effects are uncertain. There were substantial gains in water production and forage for cattle and wildlife following clear-cutting pon-

derosa pine, but in exchange there were large losses in terms of wood, aesthetics, and sedimentation. A more refined pine treatment, where one-third of a watershed was cleared in 60-foot strips, has been completed for 1 yr. There are indications of increased water, herbage, and wildlife yields from this treatment. Losses in the other values have been less than with clearcutting.—Auth. abstr.

BURGY, ROBERT H. 282

1958. Costs and benefits of converting chaparral and chaparral woodlands in California. *In* Preliminary Economic Consideration of the Arizona Watershed Program. Ariz. Watershed Symp. Second Annu. Proc., Sept. 22, 1958. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 49–58, illus.

This paper reports information gained from studies of chaparral conversion on some pilot watersheds in California. The information given refers primarily to the hydrologic study initiated in 1952 by the University of California at Davis at the Hopland Field Station. The area includes a watershed having an area of 40 acres and elevation ranging from 900 to 1,100 feet.

The program of vegetation management followed a pretreatment calibration of 4 years, beginning in 1952 and continuing through the summer of 1956. During this time precipitation, runoff, and erosion were measured. During 1956 the watershed was burned and then airplane-seeded to grass.

Increased water yield was recorded after the vegetation conversion. Increased total seasonal runoff values reported ranged from less than 1 inch during some years to as much as 10 inches during others.

COLLINGS, M. R., AND MYRICK, R. M. 283

1966. Effects of juniper and pinyon eradication on streamflow from Corduroy Creek Basin, Arizona. U. S. Geol. Surv. Prof. Pap. 491–B, 12 p., illus.

An investigation to determine the effect of juniper and pinyon removal and of controlled burning on runoff was made on the adjacent Carrizo Creek and Corduroy Creek basins, Fort Apache Indian Reservation, Ariz. The watersheds encompass areas of 237 and 213 square miles, respectively. The study was begun in 1957 with 5 years of streamflow records already existing. Thirty-eight percent of Corduroy Creek basin was modified; Carrizo Creek basin was left undisturbed. There were 7 years of premodification data (1952–58) and 5 years of postmodification data (1959–63).

Prior to this study the theory had been advanced that, if undesirable species of vegetation were eradicated from a basin, such as the one studied in this investigation, runoff would be increased and measurable and additional discrete quantities of water would be made available for appropriation. From the results of this study, however, it cannot be demonstrated that the partial clearing of Corduroy Creek basin resulted in either an increase or a decrease in water yield.—From auth. abstr.

GOODELL, B. C. 284

1951. A method for comparing the flow from a pair of experimental watersheds. Amer. Geophys. Union Trans. 32(6): 927–930.

This paper describes briefly a method developed to predict the annual streamflow of one experimental watershed from that of another in the Fraser Experimental Forest, in Colorado. The watersheds are unlike in size and topographic characteristics. They are at similar elevations. It is possible to predict the streamflow for selected months or for natural segments of the hydrograph. Likewise, the shape of the hydrograph and the total volume of flow can be established. Errors of prediction are discussed, as well as the precision required to determine the effects of treatment which might be applied to an experimental watershed.—From auth. abstr.

GOODELL, B. C. 285

1958. A preliminary report on the first year's effects of timber harvesting on water yield from a Colorado watershed, U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Sta. Pap. 36, 12 p., illus.

Appreciable increases in streamflow have followed the removal of one-half of the mature timber (pine, spruce, and fir) from the watershed of the Fraser Experimental Forest, in Colorado. The spring flood peak was increased the first year, but decreased in comparison with the control the second year. Sediment yield was low following cutting. Snow accumulation has increased in the cut strips.—From auth. sum.

HIBBERT, ALDEN R. 286

1971. Increases in streamflow after converting chaparral to grass. Water Resour. Res. 7(1): 71–80, illus.

Water yield has increased substantially on two small chaparral watersheds in central Arizona following brush control and conversion to grass. Winter precipitation is the major source of water yield. Summer rains begin in July and normally account for about one-fourth of the annual precipitation but generally have little effect on streamflow. When annual precipitation is less than 16 inches, increase in water yield resulting from treatment is likely to be less than 2 inches. However, the efficiency of the conversion for producing extra water improves with rainfall, at least up to 34 inches. At this amount of annual precipitation, the increase in flow may reach 12 inches or more, depending on seasonal distribution of the rain.—Auth. abstr.

HILL, LAWRENCE W., AND RICE, RAYMOND M. 287

1963. Converting from brush to grass increases water yield in southern California. J. Range Manage. 16(6): 300–305, illus.

In most years deep-rooted brush depleted soil moisture throughout the root zone of lysimeters and plots, and little soil water became available for streamflow. Percolation to ground water occurred under grass but not under chaparral brush.

Thirty-eight acres of canyon-bottom vegetation were cleared in an 875-acre drainage for a watershed management study. Native, shallow-rooted grasses invaded the site, but weeds and brush were killed with herbicides. Gains in streamflow per acre cleared averaged 0.7 acre-foot.

HOYT, W. G., AND TROXELL, H. C. 288

1932. Forests and streamflow. Amer. Soc. Civil Eng. Proc. 58(6): 1037–1066, illus. (Reprinted with full discussion in Amer. Soc. Civil Eng. Trans. 99: 1–111, 1934.)

The effect on streamflow of changes in forest and brush cover in the Wagon Wheel Gap area of Colorado (Bates and Henry 1928, 279) and the San Gabriel Canyon area near Azusa, Calif., are described in this paper. Changes were effected in Colorado by cutting and in California by accidental fire after accurate data had been recorded for several years.

It was concluded that forests did not "conserve the water supply," because after their removal there was an increase in average annual yield amounting to 15 percent in the Colorado mountains and 29 percent in the coastal mountain area of southern California.

Contrary to widely quoted opinion, the increase in runoff was not confined wholly to flood periods. In both the Wagon Wheel Gap area and in the southern California area, 52 percent of the increase occurred during the nonflood period.

LEWIS, DAVID C. 289

1968. Annual hydrologic response to watershed conversion from oak woodland to annual grassland. Water Resour. Res. 4(1): 59–72.

A 12-acre experimental watershed in the Sierra Nevada foothills of central California has been subjected to intensive range management practices after a 6-year calibration period. The treatment consisted of chemically killing a dense stand of oak trees and brush to improve forage production. An adjacent untreated watershed, which is geologically and hydrologically similar, provides a means of evaluating the annual hydrologic response.

Streamflow comparison shows an average annual increase of 4.5 inches in water yield. Inflow-outflow analysis shows a corresponding decrease in consumptive use of water from an average of 20 inches per year to 15 inches per year. The change in consumptive use is demonstrated in an annual water yield prediction model and in the relationship of consumptive use to precipitation. Estimates of annual potential evapotranspiration from climatological data are higher than measured consumptive use. Two methods for predicting annual consumptive use show close agreement with measured values for both oak woodland and annual grassland.—From auth. abstr.

LEWIS, D. C., AND BURGY, R. H. 290

1964. The relationship between oak tree roots and groundwater in fractured rock as determined by tritium tracing. J. Geophys. Res. 69(12): 2579–2588, illus.

The depths to which trees can extend their roots to obtain water have commonly been estimated to equal the height of the aerial portion of the plants. A detailed hydrogeologic investigation on a foothill pilot watershed has included diamond core drill holes which penetrate the fractured and jointed metamorphic rock well into the saturated zone. These holes provide observation wells for ground water measurements and access for the injection of tritiated water into the ground water zone. Over a 3-year period, injections have been made at various locations where ground water occurs at different depths from the ground surface.

In all the injection tests, significant amounts of tritiated water have been found in the water extracted from the fractured rock by oak trees. Size and species of the oak trees do not influence the uptake of the injected tritiated water from the ground water. Results of the 1962 experiment show that the oaks extend roots through the fractured rock to depths in excess of 70 feet. The number of oak trees in which the uptake of injected tritiated water has been detected indicates that all oak trees in the study area use water from the capillary zone immediately above the water table during the summer and fall months, a fact supported by observations of the decline of ground water levels during these seasons. The decline occurs at nearly the same rate regardless of the depth to ground water or the location of the well on the watershed.—Auth. abstr.

LOVE, L. D. 291

1955. The effect on stream flow of killing of spruce and pine by the Engelmann spruce beetle. Amer. Geophys. Union Trans. 36(1): 113–118.

An outbreak of the Engelmann spruce beetle on the White River Plateau of western Colorado killed the Engelmann spruce and lodgepole pine on a considerable portion of the 762-square-mile drainage basin of White River above the town of Meeker, Colo. Statistical analyses were made to compare streamflow and water content of snow for White River with similar measurements made for the 206-square-mile drainage basin of Elk River above Clark, Colo. The analyses show that the flow of White River increased after the beetle outbreak, and this increase is attributed to reduced interception of snow and to reduced transpiration by the beetle-killed trees. The average annual streamflow increased by 1.22 inches during 1941–46 and by 2.28 inches during 1947–51 as compared to the period 1937–40, after adjustment was made for climatic fluctuations.—From auth. abstr.

PASE, C. P., AND FOGEL, MARTIN M. 292

1968. Increasing water yields from timber, chaparral, and desert shrub in Arizona. *In* Water for Peace: International Conference on Water for Peace—May 23–31, 1967. U. S. Govt. Print. Off. 2: 753–764, illus.

Various methods of managing wild-land watersheds in Arizona for increased water yield are discussed.

A commercial timber harvest, by individual tree selection, did not significantly increase water yield, even when 45 percent of the basal area was removed. At the other extreme, converting moist-site mixed conifers to grass increased streamflow about 8.4 cm. per year. To determine water yield changes between these extremes, a forest stand was reduced to a basal area of 9 $m.^2$ per hectare in 1966, the minimum expected to produce good quality timber growth.

Conversion of previously burned dense chaparral cover to grassland increased water yields 8 to 25 cm. per year. Four annual aerial applications of 2,4,5–T effectively suppressed shrubs and permitted good development of herbaceous cover.

Application of sodium chloride to the surface soil in the desert shrub type resulted in an increase of 1.2 cm. in surface runoff. Quality of the runoff water was excellent for agricultural purposes (approximately 200 p.p.m. total dissolved salts).—Auth. sum.

PASE, C. P., AND INGEBO, P. A. 293

1965. Burned chaparral to grass: early effects on water and sediment yields from two granitic soil watersheds in Arizona. *In* Ariz. Watershed Symp. Ninth Annu. Proc., Tempe, Ariz., Sept. 22, 1965. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 8–11, illus.

Experiments on the Three-bar experimental watersheds were conducted by the Rocky Mountain Forest and Range Experiment Station, U. S. Forest Service, to determine factors influencing water yields from chaparral-covered lands of Arizona.

In June 1959, the 22,000-acre Boulder Mountain fire swept over the experimental area, and the watershed cover was largely destroyed. After the wildfire, most species of shrubs quickly resprouted. Resprouting shrubs on watershed *C* were sprayed with herbicides (2,4,5–T) in May for 4 successive years, beginning in 1960, to convert the watershed to grass cover. Runoff was highest on all watersheds in the first year following the fire. By the end of the fourth year, runoff from the control watershed *D* was approaching prefire conditions. In the watershed sprayed by herbicides to favor grass, the runoff was significantly increased compared to that in watershed *D*.

PASE, C. P., INGEBO, P. A., DAVIS, E. A., AND MCCULLOCH, C. Y. 294

1967. Improving water yield and game habitat by chemical control of chaparral. *In* XIV IUFRO-Kongress, München, 1967. Int. Union Forest Res. Organ. Papers I (Sect. 01–02–11): 463–486, illus.

Aerial application of 2,4,5-T for four consecutive years on a 38.6 ha. watershed in central Arizona, followed by hand application of fenuron to surviving shrubs, held crown cover of chaparral fire sprouts to 12 percent of ground surface, while sprouts on an untreated watershed increased to 56 percent. Water yield increases for the first 3 years after treatment averaged 76 mm. In the fourth year, with high rainfall, the increase was 250 mm. Chemical control resulted in higher forb and grass production and more deer use than on an adjacent untreated area. Deer forage preferences suggest the treatment was too drastic for optimum deer habitat over large areas.

Hand application of fenuron or picloram to 6-year-old fire sprouts on

northerly aspects and channel bottoms of an 18.8 ha. watershed reduced crown cover from 51 percent to 12 percent. Water yield appears to be increasing, but data are insufficient to support firm conclusions. Shrub control on cool, more moist sites with interspersed southerly aspects left as escape cover and browse forage promises to be a highly desirable form of treatment in terms of deer habitat.—From auth. sum.

PRICE, RAYMOND 295

1967. Possibilities of increasing streamflow from forest and range watersheds by manipulating the vegetative cover—the Beaver Creek pilot watershed evaluation study. *In* XIV IUFRO-Kongress, München, 1967. Int. Union Forest Res. Organ. Papers I (Sect. 01-02-11): 487–504, illus.

As post-treatment research results become available from small watersheds, they will be generally useful to land managers. However, application and evaluation of these results on large watersheds are necessary to provide economic data for management operations. Results of economic analyses will enable land managers to determine product-mix values and treatment costs on similar areas and help them decide among treatment and management alternatives. This is the ultimate objective of the watershed evaluation research on the Beaver Creek pilot watershed in north central Arizona. That part of the watershed being evaluated consists of three major vegetative types: the lower pinyon-juniper woodland; the upper pinyon-juniper woodland; and pine forest.—From auth. sum.

RICH, LOWELL R. 296

1965. Water yields resulting from treatments applied to mixed conifer watersheds. *In* Ariz. Watershed Symp. Ninth Annu. Proc., Tempe, Ariz., Sept. 22, 1965. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 12–15, illus.

This paper reports changes in water yields resulting from treatments applied to watersheds of Workman Creek, in Arizona, and describes treatments being applied to watersheds of Castle Creek on the Apache National Forest.

By the time of this report, three treatments had been completed on the Workman Creek watersheds: Two on North Fork—a small riparian cut in 1953 and an 80-acre moist-site cut and replacement of Douglas-fir and white fir forest with perennial grass in 1958; and one on South Fork—an individual tree selection timber harvest. Data taken between 1959 and 1964 from the North Fork watershed, indicate that an increase in water yields of about 55 percent resulted from removing moist-site forest but no significant results were obtained from either the riparian cut or the selection harvest.

Two Castle Creek watersheds, about 20 miles south of Alpine, Ariz., were instrumented in 1956. These watersheds are forested with ponderosa pine. In June 1965 a timber harvest cut was initiated on the West Fork.

RICH, LOWELL R. 297

1968. Preliminary water yields after timber harvest on Castle Creek, Arizona, watersheds. *In* Ariz. Watershed Symp. Twelfth Annu. Proc., Phoenix Ariz., Sept. 18, 1968. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 9–12, illus.

Within the forest type of eastern Arizona, watershed management is concerned with water supplies and ways to improve water yields. It is also concerned with other watershed products, including vegetation to control erosion, timber, forage, wildlife habitats, and areas for recreation.

Studies of watersheds of Workman Creek, in Arizona, have indicated that complete removal of forest vegetation increases water yields (North Fork) but that removal of individual trees does not necessarily increase water yields (South Fork). Studies of watersheds of Castle Creek, in Arizona, were aimed

at developing a system of timber management that would improve both water and timber yields in ponderosa pine areas.

RICH, LOWELL R. 298

1972. Managing a ponderosa pine forest to increase water yield. Water Resour. Res. 8(2): 422–428, illus.

A forest ecosystem managed for social goals of water, wood production, wildlife, scenic values, and sediment control was applied to the West Fork watershed, Castle Creek, after a 10-year calibration period. Water yields have improved significantly following this timber harvest and improvement cut. During the posttreatment period an increase of 1.4 inches of water was measured during a year of high runoff when 8.77 inches was yielded from the control watershed. In contrast, during years of low runoff when the water yield averaged 0.5 inch from the control watershed, the increase averaged more than 0.4 inch. Streamflow is intermittent. Winter precipitation has been the major source of water yields. Summer rains during June through September have accounted for nearly 46 percent of the annual precipitation but less than 10 percent of the streamflow. No measurable quantities of sediment have been trapped in the pond above the measuring weir.—Auth. abstr.

RICH, L. R., REYNOLDS, H. G., AND WEST, J. A. 299

1961. The Workman Creek experimental watershed. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Sta. Pap. 65, 18 p., illus.

The three experimental watersheds of Workman Creek lie within the humid forest type of central Arizona. These watersheds drain 1,087 acres and are a part of the Tonto National Forest.

It is desired to know the effects of timber cutting upon water yields and sedimentation for forest types such as those found on Workman Creek. Sites for plant growth vary from dry southern exposures dominated by ponderosa pine to more moist sites where Douglas-fir and white fir are important. Along stream channels bigtooth maple, Arizona alder, Arizona walnut, and aspen are found sparingly. Streamflow of the three forks of the creek was measured by 90° V-notch and Cipoletti weirs.

All alder and maple adjacent to springs, seeps, and streams on North Fork were cut in 1953, and the stumps were poisoned to prevent sprouting. An individual tree selection harvest, which removed about half of the merchantable timber, was carried out in the South Fork area. Eighty acres of moist-site forest, dominantly white fir and Douglas-fir, were cleared in 1958. The cleared areas were then planted to perennial grass.

Five years (1954–58) of annual water yields from North Fork following the removal of broadleaved trees along the stream showed no significant increase when compared with water yields from the control watershed (Middle Fork). The tree selection cut in South Fork also produced no significant water increase. Water yield from North Fork increased 0.5 inch during the first water year (Oct. 1958–Sept. 1959) following replacement of 80 acres of forest with perennial grass. Water yield the second year (Oct. 1959–Sept. 1960) increased 2.0 inches.

ROTHACHER, JACK 300

1965. Streamflow from small watersheds on the western slope of the Cascade Range of Oregon. Water Resour. Res. 1(1): 125–134.

Streamflow from small watersheds on the western slopes of the Cascade Range in Oregon are strongly influenced by a maritime climate. Although

annual precipitation is high, overland flow is almost unknown. Peak flows result largely from subsurface flow and under conditions in which both retention and detention reservoirs are almost filled during extended periods of low-intensity rainfall. Under these conditions, vegetation appears to exert a minimum influence on high streamflow. The dense vegetation of this part of the Douglas-fir region appears to exert its major influence during dry periods. Removal of vegetation from only 30 percent of a 250-acre watershed has caused a 12-28 percent increase in minimum streamflow. On a 237-acre watershed on which 80 percent of the trees were cut, the increase in low flow was 85 percent.—From auth. abstr.

See also 47, 53, 257, 258, 265.

Eastern United States

AYER, GORDON R. 301

1968. Reforestation with conifers—its effect on streamflow in central New York. Water Resour. Bull. 4(2): 13–24, illus.

Runoff from several reforested areas in central New York was compared with that from a nonforested control area. During the early 1930's, abandoned farmland was planted with small conifers which have been allowed to grow without the existing conditions being disturbed by burning, brush eradication, or denudation. The results have been a gradual reduction in winter peak runoff and total annual runoff as the trees grew. Maximum changes had occurred by about 1958; effects have been reasonably stable since then. Statistical analyses show that reforestation has reduced November-April flood peaks an average of 40 percent and annual runoff by 26 percent. There has been no effect on peak discharge during summer, on baseflow recession rates, or on annual minimum daily flows.—From Selec. Water Resour. Abstr. 1(10A): 8, 1968.

HART, GEORGE 302

1966. Forest cutting to increase streamflow in the White Mountains. New Hampshire Forest Notes. Society for the Protection of New Hampshire Forests. Concord, N. H. No. 89, 4 p., illus.

An experimental watershed was clearcut in 1965 to determine how removal of trees affects streamflow. The felled trees were left where they were so that results of the experiment would not be confused by effects of logging and skidroads.

HEWLETT, JOHN D. 303

1966. Will water demand dominate forest management in the East? *In* Soc. Amer. Forest. Proc., Seattle, Wash., Sept. 1966. p. 154–159, illus.

Experiments conducted on the Coweeta Experimental Forest, in western North Carolina, indicate that clear felling can increase water yield by a maximum of 16 inches per year. In one area there was an annual yield of 40 inches with an annual rainfall of 70 inches. After clear felling, the yield from the area increased to 56 inches. Experiments also showed that this increase of 16 inches declines until recutting and then goes back up to 16 inches.

The percentage increase in water yield from thinning seems to be linear in relation to the percentage reduction of total basal area. In one area, 50 percent of the vegetation was removed with an effort to exclude bias from the selection and removal. The increased yield of water was 8 inches per year, or 50 percent of the 16 inches produced by clearcutting. Similar ex-

perimental cuts with 25 percent and 30 percent selective removal involving riparian and commercial trees showed similar linear increases in water yield.

HEWLETT, JOHN D., AND HIBBERT, ALDEN R. 304

1961. Increases in water yield after several types of forest cutting. Int. Ass. Sci. Hydrol. Bull. [Louvain] 6(3): 5–17, illus.

Results from 11 forest cutting experiments on small watersheds at the Coweeta Hydrologic Laboratory, in western North Carolina, are presented as a summary of 20 years' experience in water yield studies. Conversion of mature forest to low-growing vegetation in this well-watered area increased the supply of water to streams in amounts varying from 5 to 16 inches per year. Increases in annual yield the first year after cutting mature hardwood forest in several ways were roughly proportional to the percentage of the stand cut on any one watershed but are not yet predictable quantitatively because of variation in soils, physiography, and orientation of small drainages. Increases tend to diminish in the years following the initial treatment, whether cutting is repeated or not, but a certain portion of the increases can be maintained indefinitely by annual recutting. In general, increases are greatest during those months when normal streamflow is lowest, but water yield can be influenced during all seasons of the year. A clearer understanding of the behavior of water in soils and plants is required before our knowledge of watershed processes will allow quantitative prediction of increased yield due to forest cutting.—Auth. abstr.

HIBBERT, A. R. 305

1969. Water yield changes after converting a forested catchment to grass. Water Resour. Res. 5(3): 634–640, illus.

A 22-acre catchment in the southern Appalachians was cleared of hardwood forest in 1958 and 1959 and seeded to Kentucky 31 fescue grass in 1959 and 1960. The amount of evapotranspiration by the grass cover was closely related to the amount of grass produced. During years when grass production was high, water yield from the catchment was about the same as or less than the expected yield from the original forest. As grass productivity declined, water yield gradually increased until it exceeded the predicted yield from the forest by over 5 inches annually. Evapotranspiration from the grassed area appeared to be greater early in the spring and less late in the summer than from the original forest cover.—From auth. abstr.

HOOVER, M. D. 306

1945. Effect of removal of forest vegetation upon water-yields. Amer. Geophys. Union Trans. 23(6): 969–975, illus.

This report describes the methods used in a study of the effect of forest cover and forest cover removal upon streamflow yields in a region of abundant rainfall in the southern Appalachian Mountains. Preliminary results are given. The study was made on the Coweeta Experimental Forest, in North Carolina.

HURSH, C. R., HOOVER, M. D., AND FLETCHER, P. W. 307

1942. Studies in the balanced water-economy of experimental drainage areas. Amer. Geophys. Union Trans. 23(2): 509–517.

This is a review of the methods involved in a study of the water cycle on the Coweeta Experimental Forest, in North Carolina, a 4,600-acre experimental area containing 30 small drainage areas, all with continuous streamflow. The natural growth of deciduous trees, abundant shrubs, and minor vegetation had not been grazed, cut, or burned for at least 20 years. Since the area is stable biologically, the transpiration and evaporation rates are relatively constant and have little to do with the fluctuation in stream-

flow. These rates vary from month to month, depending on precipitation, wind, temperature, ground water availability, and other factors.

JOHNSON, E. A., AND KOVNER, JACOB L. 308

1956. Effect on streamflow of cutting a forest understory. Forest Sci. 2(2): 82–91, illus.

Cutting the understory of laurel and rhododendron in hardwood stands decreased evapotranspiration and increased streamflow in a prehumid climate in the southern Appalachian Mountains where the understory covered more than 80 percent of the area. Based on normal precipitation, cutting increased annual streamflow, on the average, 2.0 inches for the first 6 years after treatment. It appears that eventually regrowth will restore the watershed very closely to its former vegetative condition and the effect of treatment on streamflow will disappear.—From auth. sum.

JOHNSON, E. A., AND MEGINNIS, H. G. 309

1960. Effect of altering forest vegetation on low flows of small streams. *In* General Assembly of Helsinki, July 25–Aug. 6, 1960. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 51: 257–266, illus.

The water demands of forest vegetation can draw heavily on groundwater supplies, the source of most streamflow during dry seasons, but the effects on low streamflow have seldom been demonstrated experimentally. In North Carolina, cutting a mountain hardwood forest and its woody understory increased the low flows of streams appreciably. Conversely, there was an evident decrease in low flows after pines were planted on a small Ohio watershed. Data from controlled experiments were re-analyzed to assess the low-flow responses to treatment including: (1) Flow depletion rates during rainless periods, (2) the October-November flows, (3) consecutive-day minimum flows, (4) instantaneous low flows, and (5) flow frequencies. The streamflow increases declined with time as forest cover grew back on treated units.—From auth. sum.

LIEBERMAN, J. A., AND HOOVER, M. D. 310

1951. Streamflow frequency changes on Coweeta Experimental watersheds. Amer. Geophys. Union Trans. 32(1): 73–76, illus.

LULL, HOWARD W., AND REINHART, KENNETH G. 311

1967. Increasing water yield in the Northeast by management of forested watersheds. U.S. Dep. Agr. Forest Serv. Northeastern Forest Exp. Sta. Res. Pap. NE–66, 45 p., illus.

Possibilities of increasing water yield from forested watersheds by total and partial forest removal are described in relation to methods, effectiveness, and costs. Reductions in water yield from reforestation and long-term forest protection are also discussed. Necessary precautions and safeguards for production of high quality water from treated watersheds are listed.—Auth. abstr.

MEGINNIS, H. G. 312

1959. Increasing water yields by cutting forest vegetation. *In* Woodlands and Water—Lysimeters. Symp. Hannoversch-Münden, Int. Union Geod. and Geophys., Hannoversch-Münden, Germany, Sept. 8–13, 1959. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 48: 59–68.

Forest cutting to reduce evapotranspiration loss has its advocates during water shortages. But underlying such proposals is little research to guide

prescriptions or enable predictions of response. Controlled experiments at the Coweeta Hydrologic Laboratory, in North Carolina, show large streamflow increments from clear cutting mountain hardwood forests on two small watersheds, first-year increases being 15 and 17 area inches, all as regulated base flows. The yearly increase levelled off at 11 inches after the third year where all regrowth was cut back annually, but it declined progressively on the other unit where a young coppice forest grew back. Cutting a shrub understory increased annual yield about 2 inches. Other experiments are measuring water yield response from stand density reduction, cutting cove hardwoods, and converting the native forest to pine and other cover types. Learning how to favorably influence water yields for specific situations will require much more basic research, particularly study of water use requirements of forest trees and of the related plant-soil-climatic factors governing the evapotranspiration process.—Auth. abstr.

REIGNER, IRVIN C. 313

1964. Calibrating a watershed by using climatic data. U. S. Dep. Agr. Forest Serv. Northeastern Forest Exp. Sta. Res. Pap. NE-15, 45 p., illus.

In a single-watershed calibration of the experimental Dilldown Watershed, in Pennsylvania, equations were developed for predicting annual runoff and monthly water loss or runoff. The basic relationships were developed from streamflow, climatic, ground-water, and soil-moisture records, but the final equations were expressed in terms of runoff and climatic variables only.—Auth. abstr.

REINHART, K. G. 314

1958. Calibration of five small forested watersheds. Amer. Geophys. Union Trans. 38(5): 933–936, illus.

On the Fernow Experimental Forest, in West Virginia, five forested watersheds, 38 to 96 acres in area, have been gaged by the U. S. Forest Service since 1951. The watersheds are close together, for the most part contiguous, and are similar in topography, soil, forest cover, and streamflow characteristics. The methods and problems of calibration should interest other investigators in this field because seldom has a group of watersheds been calibrated for forest watershed research to determine the effects of a range of cutting treatments. After calibration, four watersheds will be cut over, four different cutting practices will be used. One watershed will be used as a control. Effects of treatment on streamflow will then be measured.—From auth. abstr.

REINHART, K. G., AND ESCHNER, A. R. 315

1962. Effect on streamflow of four different forest practices in the Allegheny Mountains. J. Geophys. Res. 67(6): 2433–2445, illus.

After a 6-year calibration period, four forested watersheds were logged in 1957–58 with practices ranging from a commercial clearcutting to a light selection cutting. Annual streamflow increased up to 5 area-inches on the clearcut watershed the year after treatment. Most of the increase came in the growing season; from May to October 1959, increases were 3.0, 1.8, 1.4, and 0.3 area-inches for per-acre cuts of 8.5, 4.2, 3.7, and 1.7 thousand board feet, respectively. The effect on water quality was related directly to degree of care taken in logging and skidroad planning. The effects of treatments are diminishing with passage of time.—From auth. abstr.

SCHNEIDER, WILLIAM J., AND AYER, GORDON R. 316

1961. Effect of reforestation on streamflow in central New York. U. S. Geol. Serv. Water-Supply Pap. 1602, 61 p., illus.

Hydrologic data have been collected since 1932 in central New York State to determine the effect of reforestation on streamflow. Data are available for three small, partly reforested areas and for one nonreforested control area. From 35 to 58 percent of the three areas were reforested, mostly with species of pine and spruce. The trees were allowed to grow without thinning or cutting, and by 1958 these reforested areas had developed into dense coniferous woodlots. The significant reductions in total runoff are attributed to increases in interception and transpiration in the reforested areas.—From auth. abstr.

SWANK, W. T., AND MINER, N. H. 317

1968. Conversion of hardwood-covered watershed to white pine reduces water yield. Water Resour. Res. 4(5): 947–954, illus.

Mixed mature hardwoods were cleared from two Southern Appalachian experimental watersheds [Coweeta Hydrologic Laboratory in western North Carolina], and the areas were planted with eastern white pine in 1956–57. Once the pine crowns began to close, streamflow steadily declined at a rate of 1 to 2 inches per year. By 1967, water yield was 3.7 inches less from a 10-year-old pine stand on a south-facing watershed than expected water yield from the original hardwood forest. Most of the water yield reduction occurred during the dormant season and was attributed mainly to greater interception loss from white pine than from hardwoods. Because interception differences increase as white pine matures, an even greater reduction in streamflow is expected.—Auth. abstr.

TRIMBLE, GEORGE R., JR., REINHART, K. G., AND WEBSTER, HENRY H. 318

1963. Cutting the forest to increase water yields. J. Forest. 61(9): 635–640.

Is it practicable to cut a forest to increase water yield? What are the flood risks and water quality hazards involved? What are the direct costs that may be incurred, and are there losses in timber income and other forest resources to be considered? These questions are discussed in terms of the results from watershed research on the Fernow Experimental Forest, in West Virginia, a mountain hardwood forest in a region of heavy, well-distributed rainfall. Four degrees of forest cutting, ranging from a commercial clearcutting to a light selection cutting, were made on 40- to 95-acre watersheds. Increases in water yields were roughly proportional to the amount of timber removed. Increases (and with heavy cutting these were large) came mostly in the growing season—the period of greatest need. Effects of cutting on high flows were not great; periods of high flow occur most frequently in the dormant season. Regrowth of vegetation was rapid, and the effects of cutting on streamflow diminished quickly. Water quality was adversely affected by poor logging practices that resulted in erosion and sedimentation. The effects of cutting on water quality were greatest during the period of active logging and diminished soon afterward.—From auth. abstr.

WAGGONER, P. E., AND HEWLETT, J. D. 319

1965. Test of a transpiration inhibitor on a forested watershed. Water Resour. Res. 1(3): 391–396.

The glyceryl half-ester of decenylsuccinic acid (GIOSA) closes tree stomata when sprayed directly upon the underside of leaves. Regression analysis of streamflow from two small watersheds on the Coweeta Experimental Forest, in North Carolina, showed that a 12 percent reduction in transpiration might be detected as a significant increase in streamflow. Two sprays of 50 pounds of GIOSA in water applied to 30 acres of one watershed from a helicopter produced little deposit on the underside of leaves and no clear evidence of stomatal closure. Observed increases in streamflow were statistically insignificant.—Auth. abstr.

WORLEY, DAVID P., AND PATRIC, JAMES H. 320

1971. Economic evaluation of some watershed management alternatives on forest land in West Virginia. Water Resour. Res. 7(4): 812–818, illus.

Timber and water research conducted at the Fernow Experimental Forest provides a 10-year record of timber growth and streamflow increases. An approach for evaluating streamflow increases in terms of timber growth foregone is modeled. Light cutting (up to one-fourth of the timber volume) slightly increased the value of timber growth as well as the amount of streamflow. Cutting one-third to one-half of the merchantable volume sacrificed timber regrowth for streamflow gain. Cutting one-half to three-fourths of the timber volume resulted in small streamflow increases for large sacrifices of timber regrowth. Cutting three-fourths or more of the forest vegetation provided major increases in streamflow but no return from timber during the 10-year period of regrowth. Average annual water costs ranged from 0 to $1.30 per thousand gallons. Although these water costs may be invalid outside the Fernow Experimental Forest, they nevertheless suggest a magnitude for water costs under similar forest conditions.—Auth. abstr.

See also 333, 487, 539.

Old World

BANKS, C. H., AND KROMHOUT, C. 321

1963. The effect of afforestation with *Pinus radiata* on summer base flow and total annual discharge from Jonkershoek catchments. Forest. in S. Afr. [Pretoria] 3: 43–65, illus.

Streamflow data from two afforested and four unafforested experimental catchments at the Jonkershoek Forest Research Station [in the Republic of South Africa], are used in a covariance analysis to determine the effect on summer base-flow and total annual discharge of replacing the natural scrub cover by afforestation with *Pinus radiata*.

The results show a significant, progressive decrease in the stream discharge from the afforested catchments. The decrease occurs from the fourth to 12th year after afforestation, and subsequently the flow remains relatively constant but at a lower level than prior to afforestation. There is some evidence that complete protection of unafforested catchments may lead to a change in their streamflow regime. The conclusions support the general hypothesis that the hydrological effect of vegetation is proportional to its density.—Auth. abstr.

BURGER, HANS 322

1954. Einfluss des Waldes auf den Stand der Gewässer. Schweiz. Anst. Forstl. Versuchsw. Mitt. [Zurich] 31: 9–58. [In German].

A watershed experiment was started in 1903 in the Emmental Valley, Switzerland, to determine the difference in hydrological behavior of two similar watersheds. One was nearly all woodland and the other about one-third woodland and two-thirds grassland.

DAGG, M., AND BLACKIE, J. R. 323

1965. Studies of the effects of changes in land use on the hydrological cycle in East Africa by means of experimental catchment areas. Int. Ass. Sci. Hydrol. Bull. [Louvain] 10(4): 63–75.

NAKANO, HIDENORI 324

1965. Effects of changes of forest conditions on water yield, peak flow and direct runoff of small watersheds in Japan. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y., p. 551–564, illus.

Some results from experiments on forest-streamflow relations on four small experimental watersheds at the Government Forest Experiment Station in Japan over 16 to 22 years are presented.

The removal of forest vegetation increased annual runoff by 38 to 192 mm. (8 to 24 percent), low runoff by 7 to 8 mm. (74 to 84 percent), direct runoff by 28 to 58 percent, and peak flow by 69 to 114 percent. The amount of increase, even with the same changes in forest conditions, will depend upon topography, soil, and other watershed conditions, especially precipitation and antecedent soil moisture. The increase reaches the maximum just after completion of logging and thereafter diminishes with recovery of the vegetation, so that the runoff will be restored to normal with complete regrowth. This research did not consider the reasons for increases in runoff, but they were probably due to the reduction of transpiration and interception and to the decline of infiltration on soil disturbed by logging.—From auth. abstr.

PENMAN, H. L. 325

1959. Notes on water balance of the sperbelgraben and Rappengraben. Schweiz. Anst. Forstl. Versuchsw. Mitt. [Zurich] 35(1): 99–109.

Compiler's Note.—This article is discussed in Penman (1963, 511). While water loss from the woodland Emmental watershed appears greater than from the one principally covered with grass, some doubts were raised as to the accuracy of the data from this pioneer study.

WICHT, C. L. 326

1943. The variability of Jonkershoek streams. J. S. Afr. Forest. Ass. [Johannesburg] 10: 13–22, illus.

Three types of fluctuation occur in natural streams such as are being investigated at the Jonkershoek Forest Influences Research Station, in the Republic of South Africa. Spates composed of stormflow are caused by all rains strong enough to yield surface runoff. Long-term fluctuations in ground water flow are caused by the infiltration of rainwater, which increases the ground water stored in the catchment, and by evapotranspiration losses and flow of water out of the catchment area, which deplete the stored ground water. Diurnal depressions in ground water flow are caused by daily evapotranspiration losses of moisture from the streambed. By plotting all such fluctuations in flow over time, a hydrograph reflecting the character of the stream during the period of observation is obtained. It is essential to analyze such hydrographs in order to demonstrate the effects of treatment applied in the catchment areas of the streams. In this paper the main features of characteristic annual hydrographs of Jonkershoek streams are examined, and statistical measures of the variability of streamflow are suggested.—From auth. introd.

WICHT, C. L. 327

1965. Forest hydrology research in the South African Republic. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 75–84, illus.

The history of forest hydrology research in the Republic of South Africa since 1935 is similar to that of comparable concurrent research in the United States. Experiments on small watersheds, with supplementary investigations, were planned to find measures of safeguarding and, if possible, improving inadequate water supplies and for restricting floods. The research was also intended to resolve the lively controversy on whether extensive timber plantations of exotic tree species, which replace natural grass or scrub, affect streamflow beneficially or not.

The first object of forest hydrological research in South Africa is, there-

fore, to determine, unequivocally, the relative, quantitative hydrological effects of the various forms of vegetal cover produced by divergent treatments. This requires efficient experimental design, valid analysis, and correct interpretation of data. The second object is to determine the practical significance of the quantitative effects of treatments and to compute from the experimental data the relative economic value of water in each of its alternative uses.

The very limited water supplies of the Republic of South Africa are so valuable that conclusions drawn from forest hydrological research in the mountainous watershed should be unimpeachable before management based upon them is prescribed.—From auth. sum.

WICHT, C. L. 328

1965. The validity of conclusions from South African multiple watershed experiments. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 749–760, illus.

Experimental methods and analyses, applied to multiple watershed experiments in the Republic of South Africa, are discussed. The experiments are designed to test the effects on streamflow of variations in the treatments: Afforestation with exotic species, controlled burning of natural vegetation, and protection of vegetation. An integrated pattern of treatments is applied on a complex of watersheds with components closely comparable in geology, topography, and initial vegetal cover and simultaneously subject to the same or related, uncontrolled, climatic influences. Repetition of treatments at different times in different watersheds permits analyses to check and confirm results. The designs are suitable for testing long-term progressive effects of treatments, for example, of afforestation to develop normal forest.

Statistical analyses with tests of significance, previously recommended for these experiments, are frequently inadmissible because the data do not comply with the premises for valid estimates of error. Examples are given to show that conclusions from graphs are often possible, even when tests of significance cannot be validly applied. Such tests should not be applied unless the data are previously investigated to ensure that the basic assumptions may be made.—From auth. abstr.

See also 260-264, 329, 603.

STREAM AND FLOOD-PLAIN REACHES

BANKS, C. H. 329

1961. The hydrological effects of riparian and adjoining vegetation. Forest. in S. Afr.[Pretoria] 1: 31–45, illus.

This paper describes how experiments at Jonkershoek, Republic of South Africa, yield data for comparison of the consumptive use of water by the riparian and adjoining vegetation. Diurnal fluctuations in streamflow were correlated with temperature to obtain data on the consumptive use of water by the natural vegetation and plantings of *Pinus radiata*. Evidence is given of a reduction in summer base-flow discharge and a decrease in absolute daily vapor losses due to afforestation.—From auth. sum.

BOWIE, JAMES E., AND KAM, WILLIAM 330

1968. Use of water by riparian vegetation, Cottonwood Wash, Arizona. U. S. Geol. Surv. Water-Supply Pap. 1858, 62 p., illus.

The change in water use as a result of the modification of riparian vegetation was measured on Cottonwood Wash, Mohave County, Ariz. A 4.1-mile length of the stream channel was selected and divided into a 2.6-mile upper reach and a 1.5-mile lower reach. Measurements of streamflow, ground-water

levels, vegetation, and meteorological phenomena in the area defined the use of water by riparian vegetation under natural hydrologic conditions. Subsequent defoliation and eradication of the vegetation in the lower reach permitted the determination of the change in water use as a result of the modification. The computed average loss of water from the lower reach before modification was 80 acre-feet per growing season, a quantity which represented about 18 percent of the average flow entering the reach in the same period. The average loss after modification of the vegetation was 42 acre-feet per growing season, a quantity which represented about 12 percent of the average flow entering the reach in the same period.—Auth. abstr.

CROFT, A. R. 331

1948. Water loss by stream surface evaporation and transpiration by riparian vegetation. Amer. Geophys. Union Trans. 29(2): 235–239, illus.

For the period August to October 1944, evapotranspiration losses from streamflow in Farmington Creek, in northern Utah, have been estimated to be about one-third of the total streamflow. Observations were made of streamflow, wet- and dry-bulb air temperatures, evaporation from several cans exposed in the stream, and water temperature. The analysis involved consideration of fluctuations in streamflow diurnally, seasonally, with changes in weather, and with the freezing of leaves. In thickly populated areas, where culinary demands for water are great, it may be economically feasible to pipe the lower reaches of water-supply streams or to keep the riparian vegetation to a minimum.—From auth. abstr.

CULLER, RICHARD C. 332

1970. Water conservation by removal of phreatophytes. Amer. Geophys. Union Trans. 51(10): 684–689, illus.

The comparative data presented in this report indicate that removal of phreatophytes from the Gila River flood plain in southeastern Arizona produces a significant reduction in evapotranspiration from the area cleared. The evapotranspiration data for bare ground during 1967 represent a temporary condition. Bare ground cannot be considered a permanent condition on the flood plain of a major river. It might be achieved by sterilizing the soil, but this would be undesirable because of the complete unproductivity of the area and because of the erosion potential. The long-term hydrologic effects of phreatophyte removal will depend on the successful establishment of vegetation having a low consumptive use of water. Continuing maintenance will undoubtedly be required to resist invasion by such plants as saltcedar. —From auth. sum.

DUNFORD, EARL G., AND FLETCHER, P. W. 333

1947. Effect of removal of stream-bank vegetation upon water yield. Amer. Geophys. Union Trans. 28(1): 105–110, illus.

This is a preliminary report of results of a study wherein vegetation has been cut along the streambank of a 22-acre watershed on the Coweeta Experimental Forest, in western North Carolina. Previous measurements on this forest showed that complete removal of vegetation results in notable gains in water yield because of a reduction in transpiration. The cutting of riparian growth has resulted in an increase in water yield of sufficient magnitude to be significant in water-resource management

Preliminary examination of the data immediately following cutting showed virtual elimination of the diurnal fluctuation during the growing season. This indicates that the vegetation immediately adjacent to the stream is making appreciable demands upon ground water supplies contributing directly to streamflow.

It can be concluded, therefore, that important gains in water yield during the growing season in the southern Appalachian Region may be realized with relatively little effort by eliminating the transpiration draft of riparian

vegetation. This procedure can be of much practical value for municipal and industrial watersheds during drought years, when even small increases in yield are of unusual importance.—From auth. abstr.

INGEBO, PAUL A. 334

1971. Suppression of channel-side chaparral cover increases streamflow. J. Soil Water Conserv. 26(2): 79–81, illus.

Shrubs and trees along well-defined stream channels in a 246-acre chaparral-covered watershed in central Arizona were chemically suppressed in 1967. Both duration and volume of streamflow increased in the 2 years following treatment. Streamflow, which is normally intermittent during summer and fall, became continuous. In 1968 and 1969, flow increased 0.63 and 0.97 area inches (32 and 54 percent), respectively, or in terms of the treated area only (15 percent of the watershed), 4.1 and 6.3 inches, respectively. Most of the increase in volume came during the time of major flows, December through April. Shrub and tree kill on the treated area will probably exceed 80 percent. Native grasses and forbs are increasing on the treated area.—Auth. abstr.

MEYBOOM, P. 335

1965. Three observations on streamflow depletion by phreatophytes. J. Hydrol. [Amsterdam] 2(3): 248–261.

Phreatophytes cause streamflow losses under natural and regulated flow conditions, whether the stream is influent or effluent. Indirect losses are said to occur whenever ground water is intercepted by the vegetation before it reaches the stream. This type of depletion is common under conditions of natural drainage in valleys where the water table lies within 7 feet of the surface and where it has a gradient of more than 0.01.

Direct losses from the stream occur in a zone of induced infiltration, the width of which depends on the relation between the phreatophytic fluctuations and the transverse water-table gradient in the valley. Direct losses can result also from bank storage effects brought about by water releases from a reservoir. Extreme streamflow depletion takes place when the stream dries up during the summer. This condition is characteristic for places where the consumptive use of the vegetation temporarily exceeds the combined supply of stream discharge and groundwater inflow.—From auth. abstr.

QASHU, HASAN K., AND EVANS, D. D. 336

1967. Water disposition in a stream channel with riparian vegetation. Soil Sci. Soc. Amer. Proc. 31(2): 263–269.

Water losses along stream channels in the semi-arid Southwestern United States are of utmost importance in relation to water disposition and water yields from a watershed. This paper describes an analysis used for estimating water disposition along a reach of a natural stream channel with riparian vegetation and impermeable bedrock at a shallow depth. Results for one annual cycle are presented which indicate the quantity of water removed from the stream channel reach by various processes.

Methods adapted for the particular set of conditions were used in measuring subsurface water flow and water storage in the channel alluvium. Subsurface water flow was calculated from Darcy's equation. Water storage in the channel alluvium was estimated from water content, water-table elevation, specific yield and volume of alluvium measurements.

Four distinct water use periods were apparent within a yearly cycle, each expressed by a separate water balance equation. Water losses by evapotranspiration were estimated from these equations. For example, 9 mm. of water were estimated to be lost per day by transpiration of the riparian vegetation during the months of May and June, a time of water shortage in the area. Total depth of annual water loss by evapotranspiration from the channel reach was estimated to be 131 cm. of water (4.3 acre-feet per acre).—From auth. abstr.

REIGNER, IRVIN C. 337

1966. A method of estimating streamflow loss by evapotranspiration from the riparian zone. Forest Sci. 12(2): 130–139, illus.

Conservative values of daily streamflow loss by evapotranspiration from the riparian zone were obtained by hydrograph analysis; data from the Dilldown Watershed, in northeastern Pennsylvania, were used. The two highest peaks of a series of diurnal fluctuations were connected by a straight line, representing the potential ground-water flow for a series of days between storm flows. The series should ideally be no longer than 5 days. After data on a sufficient number of daily riparian water losses were obtained, they were used as observations for the dependent variable in multiple-regression analysis. In this investigation, 62 samples, occurring during June, July, and August in 1955 and 1956, were used. An equation was derived which estimated riparian water losses with a relatively high degree of accuracy.—From auth. abstr.

REIGNER, IRVIN C., SOPPER, WILLIAM E., AND JOHNSON, ROY R. 338

1968. Will the use of 2,4,5-T to control streamside vegetation contaminate public water supplies? J. Forest. 66(12): 914–918.

Riparian vegetation along two small headwater streams in Pennsylvania and New Jersey was treated with 2,4,5-T. Water samples were collected immediately after treatment and periodically thereafter for three weeks. Odor tests were used to determine the degree of contamination. Results indicated that only slight contamination occurred within the treated sections of streams immediately after treatment and, in two instances, after the first large storm. No contamination was detected downstream. Vegetation analysis one year after treatment indicated that the ester formulation had completely killed 70 to 81 percent of the stems and that the emulsifiable acid had killed 58 to 78 percent. Results of this study provide additional evidence that phenoxy herbicide, if applied with normal precautions, can be used on municipal watersheds without creating any water contamination.—Auth. abstr.

ROWE, P. B. 339

1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. J. Forest. 61(5): 365–370, illus.

A test of applied watershed management carried on in Monroe Canyon on the San Dimas Experimental Forest, in southern California, has shown that streamflow yields can be appreciably increased by clearing the deep-rooted woodland-riparian vegetation from the canyon bottom. The increases in flow were especially important because they occurred primarily in summer and in the initial period of soil wetting during succeeding rainy seasons, when streamflow was lowest and water most needed.

During the one rainy season of heavy precipitation and continuously wet soils, the removal of the woodland-riparian vegetation had no appreciable effect on streamflow, peak discharge, or erosion rates. However, during wetting periods and during the one rainy season of light precipitation, streamflow yields, particularly during storms, were considerably increased. Streamflow was inadequate to produce sediment movement in either the treated or control watersheds during these wetting periods. Removal of the tree-brush cover shading the stream course resulted in an increase in the algae content of the late spring and summer flows but had no other detectable effect on water quality.

These first results show that, while streamflow can be increased by removal of the canyon-bottom vegetation, this kind of treatment, to be most successful, should be limited to carefully selected areas with conditions of climate, vegetation, soil, and water capable of yielding the desired increases; that is, to areas in which (1) the water supply is adequate to exceed

evapotranspiration losses after treatment, (2) the water table or zone of saturation is within reach of the heavy water-using woodland-riparian vegetation, and (3) the canyon-bottom soils overlaying the water table are of sufficient extent and depth to permit reduction in evapotranspiration if the deep-rooted vegetation is eliminated.—From auth. abstr.

RYCROFT, H. B. 340

1955. The effect of riparian vegetation on water-loss from an irrigation furrow at Jonkershoek. J. S. Afr. Forest. Ass. [Johannesburg] 26: 2–8, illus.

Water losses from the soil and streams are caused by several factors, the most important of which is probably transpiration, especially during periods of hot, dry weather. This paper describes such losses and, as a result of an experiment carried out at Jonkershoek, Republic of South Africa, suggests that water loss can be reduced by removing riparian vegetation during periods of acute water shortage.—From auth. sum.

TAYLOR, COLIN A., AND NICKLE, HARRY G. 341

1933. Investigations in Coldwater Canyon. *In* Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 88–121, illus.

Riparian water losses were studied in Coldwater Canyon near San Bernardino, Calif. Trees in the area were primarily alder, bay (California-laurel), maple, willow, and sycamore. The combined evaporation and transpiration by the native vegetation growing in the canyon was determined by measuring water flow at various points along the channel. The controls were on bedrock so that the amount of water entering the upper end of each section of the channel was known, as well as the amount leaving each section.

The results of this study show a loss from the lower section (average elevation 2,400 feet) of the canyon for the 6-month period from May to October 1932 of 5.3 acre-feet per acre of canyon fill. For the same period in the upper section of the canyon (average elevation 2,800 feet), the loss was found to be at the rate of 4.2 acre-feet per acre of canyon-bottom fill.

The evaporation from the water surfaces of the stream was shown to be only a small part of the total water loss in this shaded canyon. The maximum loss in the canyon occurred during August 1932, being at the average rate of 0.44 acre-inch per acre per day in the lower section; the same section in October had an average rate loss of 0.26 acre-inch per day. Enough water is consumed during the growing season along each mile of canyon similar to the lower section to meet the annual irrigation requirements of approximately 16 acres of citrus.

THOMSEN, B. W., AND DENNIS, P. E. 342

1963. Water salvage possibilities on Sycamore Creek, Maricopa County, Arizona. *In* Water Conservation from Mountains to Desert. Ariz. Watershed Symp. Seventh Annu. Proc., Phoenix, Ariz., Sept. 18, 1963. Ariz. Water Resour. Comm. and Watershed Manage. Div., State Land Dep. p. 16–18, illus.

The object of the U. S. Geological Survey project discussed in this paper is to determine the surface inflow to Sycamore Creek, in Arizona, at various points and the total outflow from the Sycamore Creek drainage basin into the Verde River system—both on the surface and underground. The information obtained and the methodology developed here may be useful in making an economic analysis of the feasibility of water salvage in similar drainage basins in southern Arizona and elsewhere in the West.—From auth. introd.

THOMSEN, B. W., AND SCHUMANN, H. H. 343

1968. Water resources of the Sycamore Creek watershed, Maricopa County, Arizona. U. S. Geol. Serv. Water-Supply Pap. 1861, 53 p., illus.

The Sycamore Creek watershed is representative of many small watersheds in the Southwest where much of the streamflow originates in the mountainous areas and disappears rather quickly into the alluvial deposits adjacent to the mountains. Five years of streamflow records from the Sycamore Creek watershed show that an average annual water yield of 6,110 acre-feet was obtained from the 165 square miles (105,000 acres) of the upper hard-rock mountain area, which receives average annual precipitation of about 20 inches. Only a small percentage of the annual water yield, however, reaches the Verde River as surface flow over the 9-mile reach of the alluvial channel below the mountain front. Flows must be more than 200 cubic feet per second to reach the river; flows of less than this rate disappear into the lower alluvial area and are stored temporarily in the ground-water reservoir; most of this water is released as ground-water discharge to the Verde River at a relatively constant rate of about 4,000 acre-feet per year. Evapotranspiration losses in the lower alluvial area are controlled by the depth of the water table and averaged about 1,500 acre-feet per year. —Auth. abstr.

TSCHINKEL, HEINRICH MICHAEL 344

1963. Short-term fluctuations in streamflow as related to evaporation and transpiration. J. Geophys. Res. 68(24): 6459–6469, illus.

This paper develops a method of relating fluctuations in streamflow during long dry periods to evaporation from a pan. Data from the East Fork of San Dimas Creek, Los Angeles County, Calif., were used. The mechanism of the fluctuations is explained by deriving water-balance equations for the riparian zone. On the basis of this method, it is possible to compute evapotranspiration losses from the watershed during the dry season by measuring the difference between the actual streamflow and a "potential" streamflow depletion curve which represents streamflow in the hypothetical situation of absolutely no evaporation.—From auth. abstr.

TSUKAMOTO, YOSHINORI 345

1960. Evapo-transpiration from ground water reservoirs in a small watershed. Jap. Forest. Soc. J. [Tokyo] 42(1): 5–9, illus.

For Higashiyama watershed, in Tokyo University Forest, in Aiti, central Japan, the value (1.45 mm. per day) of evapotranspiration from ground water reservoirs by riparian vegetation in summer was computed by using the difference between the ground water depletion curve in winter (January and February) and that in summer (July and August). The method of computing daily values of this water loss by riparian vegetation is presented on the basis of Thornthwaite's formula for determining potential evapotranspiration.—From auth. abstr.

See also 47, 60, 142, 149, 257, 287, 288, 362–366, 677, 682, 684.

GROUND-WATER WELLS

GARY, HOWARD L. 346

1962. Removal of tamarisk reduces water-table fluctuations in central Arizona. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Res. Note 81, 6 p., illus.

This publication reports on a study made to determine whether removal of vegetation from a small area would reduce diurnal water table fluctuations. Fluctuations were significantly reduced after tamarisk and arrowweed

were removed from an area 25 feet in diameter around one ground-water well site. Two enlargements of the cleared area around the well site, however, did not further decrease water-table fluctuations.—From auth. sum.

GARY, HOWARD L., AND CAMPBELL, C. J. 347

1965. Water-table characteristics under tamarisk in Arizona. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Res. Note RM-58, 7 p., illus.

This publication describes characteristics of the water table under *Tamarix pentandra* in central Arizona. It discusses water-table fluctuations in 39 ground-water wells within a circular area, about 40 feet in diameter, before and after removal of vegetation. Pumping tests (see Theis and Conover 1951, 357) to simulate natural diurnal fluctuations in selected wells were not satisfactory. Evapotranspiration losses were not determined.—From auth. abstr.

HEIKURAINEN, LEO 348

1965. Effect of cutting on the ground water level on drained peatlands. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29-Sept. 10, 1965. Pergamon Press, N. Y. p. 345–355, illus.

The objective of this study was to determine the effect of various cutting intensities on the ground-water level. The study areas were drained peatlands, where the ground-water level was close to the soil surface. The results showed that cutting strongly influenced a rise in the water level. Clearcutting of a stand with 100 $m.^3$ per hectare caused the water level to rise as much as 40 cm. Thinning also causes the water level to rise, the amount of rise being dependent upon the intensity of thinning.

The basic reason for the observed rise in the level of ground water is the reduction in transpiration and interception, caused by cutting. When the measured rise in water level is converted to actual soil-water storage, it is evident that this amount of water is much smaller than would be expected from the data on the observed reduction in transpiration and interception as a result of cutting. The reason for this discrepancy is that the runoff is greater from areas with a high ground-water level than from areas with a low ground-water level. The rise of water level caused by cutting is, therefore, dependent not only upon the intensity of cutting but also the intensity of drainage.—From auth. abstr.

HOLSTENER-JORGENSEN, H. 349

1965. Influence of forest management and drainage on ground water fluctuations. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc. Penn State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 325–333, Illus.

A study was conducted to investigate the influence of clearcutting and shelterwood cutting in a beech stand growing on a soil with a high ground-water level. Results indicate that the water table became considerably higher during the growing season. As a Norway spruce plantation established on the clearcut area developed, the water table was again lowered during the growing season. The same results were obtained as the shelterwood stand closed again following cutting. Effects on ground water of a reduction of root system caused by flooding a 116-year-old beech stand are presented. The application of these results to watershed management is discussed.—From auth. abstr.

MEINZER, OSCAR E. 350

1923. Outline of ground-water hydrology, with definitions. U. S. Geol. Surv. Water-Supply Pap. 494, 71 p., illus.

This paper provides excellent definitions of terms related to ground-water hydrology, including the first published use of the word "phreatophyte".

MEINZER, OSCAR E. 351

1927. Plants as indicators of ground water. U. S. Geol. Surv. Water-Supply Pap. 557, 95 p., illus.

The common phreatophyte species are listed and some general information is given about them with respect to growth habit, geography, depth of water table reached, and quality of ground water endured. Saltcedar (tamarisk) is not mentioned.

MEINZER, OSCAR E. 352

1932. Outline of methods for estimating ground-water supplies. U. S. Geol. Surv. Water-Supply Pap. 638-C, p. 99–144.

This paper is a discussion and outline of the general conditions of the permeable rock formations which serve as underground reservoirs or as underground conduits for ground water. While the paper deals with all methods relating to quantitative measurement of ground-water supplies, pages 107–110 discuss methods for estimating discharge by evaporation from soil and transpiration from plants.

MEYBOOM, PETER 353

1967. Ground water studies in the Assiniboine River drainage basin. Part II: Hydrologic characteristics of phreatophytic vegetation in south-central Saskatchewan. Can. Dep. Energy Mines and Resour. Geol. Surv. Can. Bull. 139, 58 p., illus.

Seasonal ground-water consumption by phreatophytes in south-central Saskatchewan ranges from 2.5 inches to more than 40 inches. During 1963 and 1964, the average ratio between ground water consumption and water losses from a class *A* evaporation pan was 0.58, with a range from 0.09 to 1.26.

The amount of ground-water consumption is determined by, among other factors, the depth to the water table. Herbs and shrubs stop using ground water when the water table is more than 7 feet below the surface; for trees, the threshold values may lie around 14 feet.—From auth. abstr.

RAMSAHOYE, L. E., AND LANG, S. M. 354

1961. A simple method for determining specific yield from pumping tests. U. S. Geol. Surv. Water-Supply Pap. 1536-C, p. 41–46.

A simpler solution which greatly reduces the time necessary to compute the specific yield [of a water-table aquifer] by the pumping-test method of Remson and Lang (1955, 355) is presented. The method consists of computing the volume of dewatered material in the cone of depression and comparing it with the total volume of discharged water. The original method entails the use of a slowly converging series to compute the volume of dewatered material. The solution given herein is derived directly from Darcy's law.—Auth. abstr.

REMSON, IRWIN, AND LANG, S. M. 355

1955. A pumping-test method for the determination of specific yield. Amer. Geophys. Union Trans. 36(2): 321–325, illus.

The specific yield of a water-table aquifer is one measure of the amount of water within the aquifer that is available for recovery (development). It is expressed as a percentage or decimal fraction of the total volume of material of which the aquifer is composed. The specific yield may be determined during the course of an equilibrium pumping test by comparing the volume of dewatered material in the cone of depression with the total volume of discharge water. An equation is developed theoretically that expresses the volume of dewatered material in terms of test data. A related equation indicates the magnitude of losses at the pumped well. These equations were tested by applying them to test data tabulated in ground-water literature.—Auth. abstr.

ROBINSON, THOMAS W. 356

1967. Effect of evapotranspiration draft by phreatophytes on the ground-water balance. *In* Congress, Int. Ass. Hydrol., Hannover, Germany, 1967. Int. Ass. Hydrol. 7: 347–351, illus.

The seasonal effect of evapotranspiration draft on the water table in various areas of phreatophytes is discussed in full in this paper. Reports on other studies of the magnitude of ground-water draft by phreatophytes are included: Lee (1912, 114) indicated that 17,000 hectares of phreatophytes used slightly less than 100 million cubic meters of water; Gatewood and others (1950, 364) indicated that about 3,800 hectares of phreatophytes in Safford Valley, Ariz., used 28 million cubic meters of ground water—75 percent was used by saltcedar; Mower and others (1964, 67) indicated that from 1956 to 1958, along the Pecos River between Acme and Artesia, N. Mex., 17,000 hectares of phreatophytes used about 91 million cubic meters of water a year.—From auth. sum.

THEIS, C. V., AND CONOVER, C. S. 357

1951. Factors for consideration in study of salvage of water used by phreatophytes. *In* Report to the Saltcedar Interagency Council, Saltcedar Interagency Task Force, Albuquerque, N. Mex. Append. IV. 12 p. Processed.

To determine the use of water by phreatophytes and possible effects of their eradication upon the water levels and quality of water, a selected area should be intensively studied before and after eradication of saltcedar. It is suggested that the following program of investigation would actually measure the amount of water used by phreatophytes: (1) A plot of at least several acres not subject to flooding and having a more or less definite geometrical shape would be selected for eradication of saltcedar; (2) lines of shallow observation wells should be established in the plot and in considerable areas surrounding it; (3) after water levels have been measured for at least 2 years to obtain antecedent conditions, the vegetation should be removed; (4) until stabilized conditions occur following revegetation, the water levels should continue to be measured in the wells in the plot and surrounding areas to ascertain the changes in water level that it is presumed will occur in the area if appreciable changes have been made in evapotranspiration; and (5) after sufficient data on water levels, water quality, and soil characteristics have been gathered, a number of small pumps should be installed and means provided to measure the discharge. The pumping rates should be adjusted so that the water level will be lowered to approximately the level prevailing before eradication. The discharge will then approximate the amount of water used by the plants.—From auth. sum.

TROUSDELL, KENNETH B., AND HOOVER, MARVIN D. 358

1955. A change in ground-water level after clearcutting of loblolly pine in the coastal plain. J. Forest. 53(7): 493–498.

This paper examines the relationship of the level of the water table and the logging of timber above the water table. Measurements showed the water table was highest in clearcut strips, lower at stand edges, and the lowest within stands.

TROXELL, H. C. 359

1936. The diurnal fluctuations in the ground-water and the flow of the Santa Ana River and its meaning. Amer. Geophys. Union Trans. 17(2): 496–504.

The paper discusses the diurnal fluctuations that occur in the flow of the Santa Ana River and the adjacent ground water. These fluctuations are caused primarily by transpiration from plants and evaporation from soil and

water surfaces. These daily changes can be used to determine water losses from river sections, but certain errors in White's method (1932, 361) were pointed out.

URIE, DEAN H. 360

1965. Influence of forest cover on ground-water recharge, timing and use. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y. p. 313–324, illus.

Methods are presented for determining the net water yield of forest lands on coarse-textured glacial drift by the analysis of changes in ground-water storage. Changes in ground water storage due to seepage flow, evapotranspiration, and recharge from percolating precipitation are separated by graphical interpretation of recording-well records. Comparisons of three forest cover conditions (deciduous species, pine plantations, and pine-oak mixtures) in northwestern lower Michigan showed that, over the period October 1961 to September 1963, the net annual water yield of deciduous forests exceeded the yield of pine plantations by an average of 2.6 inches; and it exceeded that of mixed pine-oak stands by 3.0 inches. These differences were associated with deeper snowpacks in the deciduous forests and longer evapotranspiration periods in pine than in hardwoods.—From auth. abstr.

WHITE, WALTER N. 361

1932. A method of estimating ground-water supplies based on discharge by plants and evaporation from soil. U. S. Geol. Surv. Water-Supply Pap. 659-A, 105 p., illus.

The amount of available ground-water supplies can be estimated by measurement of daily fluctuations of the water table. This approach was used in a study in Escalante Valley, southwestern Utah. The procedure was to install observation wells equipped with water-stage registers at representative locations in the area under consideration to obtain graphic records of the ground-water fluctuations. The diurnal cycle, as indicated by the ground-water table, represents a curve showing the relation of consumptive use to ground-water discharge or recharge.

The records obtained from 75 observation wells showed that during the growing season there was a marked daily fluctuation of the water table nearly everywhere. The maximum daily drawdown amounted to about 1½ inches in greasewood and shadscale, 2½ inches in alfalfa, 3¾ inches in saltgrass, and 4½ inches in sedges and associated marsh grasses. These fluctuations did not occur in plowed fields, cleared land, tracts of sagebrush, and tracts where the water table is far below the surface.

To determine specific yield of the soils, cylinders were driven near observation wells so as to enclose columns of undisturbed soil in the zone in which the fluctuations take place, and the rise and fall of the water table in the enclosed columns after the addition or subtraction of measured amounts of water were carefully noted. The amount of ground water discharged daily by the plants was then computed by the formula $q = y(24r \pm s)$, in which q is the depth of ground water withdrawn in inches, y is the specific yield of the soil in which the daily fluctuation of the water table takes place, r is the hourly rate of rise of the water table in inches from midnight to 4 a.m. (when it was determined that transpiration and evaporation were practically nil), and s is the net fall or rise of the water during the 24-hour period in inches. In field experiments the quantities on the right-hand side of the formula, except the specific yield, can be readily determined from the automatic records of water-table fluctuations.—From auth. abstr.

See also 364, 366, 682, 684.

BLANEY, HARRY F., EWING, PAUL A., ISRAELSEN, O. W., ROHWER, CARL, AND SCOBEY, FRED C. 362

1938. Water utilization. *In* Regional Planning, Part VI—Upper Rio Grande. Natl. Resour. Comm. p. 293–427, illus.

This paper provides extensive data on water supply and water use by irrigation and discusses methods of computing water use and water losses. Earlier studies and reports on consumptive use of water along the Rio Grande are fully summarized. The consumptive water use studies conducted by the Bureau of Agricultural Engineering, U. S. Department of Agriculture, in San Luis Valley, Middle Rio Grande Valley, and Mesilla Valley are outlined.

Three methods were used to estimate valley consumptive use: *A*. The inflow-outflow method, which is the measurement of the amount of water flowing into and out of a given area, including precipitation and change in ground-water storage; *B*. the integration method, which is the summation of the products of consumptive use for each crop times its area, plus the consumptive use of native vegetation times its area, plus water surface evaporation times water surface area, plus evaporation from bare land times its area; and *C*. the Hedke heat-consumption method, which is the application of a linear relation between the consumptive use of water and the heat available for production of crops each month and for the season (C. R. Hedke, unpublished).

Method *A* was used in most of the studies of determining consumptive use and was held to be the most reliable when compared to the other methods, but the Hedke method was seriously considered and felt to have application after more comprehensive research into the relation of available heat to water loss.

The report includes a discussion of soil-moisture plot measurements in various crops and tanks planted to wheat, potatoes, cotton, alfalfa, saltgrass, willows, and cattails. Improvements in the soil-moisture plot and tank techniques developed since the southern California studies (California Division of Water Resources 1933, 59) were incorporated, but the data collected in the Rio Grande studies are only indicative because they were operated in a short period of less than one season in 1936; in spite of this limitation they have been frequently quoted.

FORD, P. M. 363

1958. Preliminary analysis of use of water by phreatophytes in Safford Valley, Arizona. U. S. Bur. of Reclam., Denver, Colo. 11 p., illus. Processed.

This paper presents an analysis of results obtained in an intensive study conducted by the U. S. Geological Survey in 1943–1944 (Gatewood, Robinson, Colby, and others 1950, 364) to determine the amount of water consumed by phreatophytes in areas of Safford Valley, Ariz.

The analysis of the draft on ground water by phreatophytes in relation to depth to water and other variables affecting consumptive use indicates that, through a 5-foot lowering of the water table, salvage of 27,000 acre-feet annually could be realized. Areas involved in the study were the Glenbar-Fort Thomas, Fort Thomas-Black Point, and Black Point-Calva reaches.

GATEWOOD, J. S., ROBINSON, T. W., COLBY, B. R., HEM, J. D., AND HALPENNY, L. C. 364

1950. Use of water by bottom-land vegetation in lower Safford Valley, Arizona. U. S. Geol. Surv. Water-Supply Pap. 1103. 210 p., illus.

This monumental research effort on the ways of determining water loss from phreatophytes is probably the most complete study ever attempted on this problem. Many of the approaches were pioneering in character, and while they often did not prove to be practical, they represent a very thorough approach to methods of determining evapotranspiration losses from phreatophytes.

The study was in lower Safford Valley, Graham County, Ariz., is an alluvial lowland plain, with some irrigated farmlands and a belt of natural vegetation in the bottom land along the river consisting of phreatophytes, principally saltcedar, baccharis, cottonwood, and mesquite. The annual use of water by the vegetation was investigated in 1943 and 1944 to supply the basic data for estimating the quantity of water that might be saved if such bottom-land vegetation were destroyed.

Six methods of determining use of water were applied during the investigation: Tank, transpiration well, seepage-run, inflow-outflow, chloride-increase, and slope seepage. These methods are described in detail with clear discussions of their applicability to river-reach studies of water losses.

Although the methods differed greatly, the figure for use of ground water computed by each method was within 20 percent of the mean determined by averaging the results of all six methods.

Based on the results obtained by the six methods, the total use of water by vegetation during the 12-month period ending September 30, 1944, was 28,000 acre-feet in a total of 9,303 acres in the 46-mile reach of Gila River from Thatcher to Calva. Of the total water used, 23,000 acre-feet were derived from the ground-water reservoir and the remainder was derived from precipitation on the area. Of the 23,000 acre feet, more than 75 percent was used by saltcedar.

A comparison by species for the study year shows that use of water by phreatophytes common to lower Safford Valley, computed for 100-percent volume density, was (in acre-feet per acre) saltcedar, 7.2; baccharis, 4.7; cottonwood, 6.0; mesquite, 3.3.

TAYLOR, COLIN A. 365

1934. Transpiration and evaporation losses from areas of native vegetation. Amer. Geophys. Union Trans. 15(2): 554–559, illus.

This article reports on several methods of measuring loss of water by transpiration and evaporation from different areas of native vegetation. Water loss in southern California by transpiration and evaporation from areas of native vegetation may range from 1 acre-foot per acre per year to 6½ acre-feet per acre per year, depending on rainfall or depth to accessible ground water.

YOUNG, ARTHUR A., AND BLANEY, HARRY F. 366

1942. Use of water by native vegetation. Calif. Dep. Public Works Div. Water Resour. Bull. 50, 154 p., illus.

The purpose of this bulletin is to bring together the results of studies of consumptive use of water by a number of species of native vegetation. The results are those determined by the Division of Irrigation, Soil Conservation Service, U. S. Department of Agriculture, for various western climatic conditions and by other agencies. Such studies have been carried on for many years. The bulletin discusses four general methods by which consumptive use of water by native vegetation has been determined: Tank studies, soil-moisture investigations, stream-flow studies, and water-table fluctuations.—From auth. introd.

See also 684.

PROCESSES INVOLVED IN WATER LOSSES BY EVAPOTRANSPIRATION

GENERAL DISCUSSION OF CLIMATIC FACTORS

BUDYKO, M. I. 367

1963. Evaporation under natural conditions. (Isparenie v estestvennykh usloviyakh. Gidrometeorol. izdatel'stvo, [Leningrad] 1948.) Trans. from Russian, 1948. Israel Program for Sci. Trans. 751 (OTS63-11061), 130 p. Jerusalem, Israel.

This monograph surveys basic studies on evaporation under natural conditions and presents the results of investigations conducted during the past few years in Russia. One of the main tasks of the studies was the development of physical methods for calculating evaporation from land surfaces which would permit the determination of the other terms of the water balance.—From auth. foreword.

GEIGER, RUDOLF 368

1965. The climate near the ground. 4th ed. Harvard Univ., Press. Cambridge, Mass. 611 p.

This is a textbook on microclimatology; it includes a full review of the extensive literature on the subject.

LIST, ROBERT J. 369

1963. Smithsonian meteorological tables. 6th ed. Smithsonian Inst., Washington, D.C. 527 p.

This book includes tables giving possible hours of sunshine at various latitudes for application in meteorological formulas.

NOFFSINGER, TERRELL L. 370

1966. Solar radiation—adequacy of present U.S.A. and world network. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 62-64, illus.

The adequacy of existing radiation networks varies according to the use to be made of the data. Since the synoptic programs of most meteorological services generally do not use radiation data for forecasting, the networks frequently have a relatively low priority in terms of funds for maintenance, modernization, and expansion. In the United States there are no operational networks for net radiation or for spectral distribution of radiation. The network for direct solar radiation and diffuse radiation is plagued with the problems enumerated above. Requirements levied by groups of potential radiation-data users stating accuracy and spatial distribution needed would probably be an effective stimulus for overcoming the limitations and inadequacies of existing networks.—From auth. sum.

REIFSNYDER, W. E. 371

1967. Forest meteorology: the forest energy balance. Int. Rev. Forest Res. 2: 127-179.

This paper is a review covering the energy balance of a forest as a whole and its components, the energy balance of leaf surfaces and other vegetative elements, the energy balance of a single tree, and the total energy budget of the forest.

REIFSNYDER, WILLIAM E., AND LULL, HOWARD W. 372

1965. Radiant energy in relation to forests. U. S. Dep. Agr. Tech. Bull. 1344, 111 p., illus.

This bulletin reviews, for foresters and those interested in the forest com-

plex, the fundamentals of short- and long-wave radiation, of radiation measurement, and of certain radiation relationships important in the forest. It first considers the physical laws of radiation and the solar energy that reaches the forest. The important unifying concept of the radiation balance is presented. Details of the principles and practices of radiation measurements are discussed next. Primary emphasis is given to the kind of measurements desired, when and where to take them, and how to take them.

The manner in which the forest absorbs, reflects, radiates, and transmits radiant energy is also presented. Three aspects of the forest-energy relationship are discussed: Forest transpiration, snowmelt, and forest growth. These aspects were selected because of their general importance in forestry and because the writers had some familiarity with background literature on them.

A startling contrast exists between our considerable physical knowledge of radiant energy and its measurement and the scarcity of the application of this knowledge to furthering our understanding of forest-radiation relationships.—From auth. preface.

VAN WIJK, W. R. (ed.) 373

1963. Physics of plant environment. John Wiley & Sons, Inc., New York. 382 p.

In the first chapter of this book, some examples of a physical approach to a quantitative understanding of the response of plants to environmental conditions are briefly discussed. In the other chapters only the physics of the environment itself is treated.

WEBB, E. K. 374

1965. Aerial microclimate. *In* Agricultural Meteorology, P. E. Waggoner (ed.). Meteorol. Monogr. 6(28): 27–58.

This article deals with the small-scale processes which dominate the atmospheric boundary layer up to a few tens of meters above the ground.

EVAPORATION FROM WATER, SOIL, AND LAND SURFACES

Free Water Surfaces

BLANEY, HARRY F. 375

1933. Evaporation from free water surfaces. *In* Water Losses under Natural Conditions from Wet Areas in Southern California. Calif. Dep. Public Works Div. Water Resour. Bull. 44: 122–139, illus.

A cooperative, experimental key station was established at Baldwin Park, Calif., for the purpose of correlating the evaporation data collected by various organizations and for determining factors that could be used to reduce the observations on various types of evaporation pans to a comparable basis. No conclusions were reached as to correlating factors. Extensive evaporation data are included from many other stations in southern California.—From auth. sum.

BLANEY, HARRY F., AND COREY, GILBERT L. 376

1955. Evaporation from water surfaces in California. Calif. Dep. Public Works Div. Water Resour. Bull. 54-B, 98 p.

This report brings up to 1955 the evaporation records published in California Division of Water Resources Bulletins 54 and 54-A (Young 1947, 386 and 1948, 387) covering the period 1881–1946.

KOHLER, MAX A. 377

1954. Lake and pan evaporation. *In* Water-loss Investigations: Lake Hefner Studies, Technical Report. U. S. Geol. Surv. Prof. Pap. 269: 127–148.

Detailed data are given comparing lake and pan evaporation; these data have served as a basis for development of later formulae.

KOHLER, M. A., NORDENSON, T. J., AND FOX, W. E. 378

1955. Evaporation from pans and lakes. U. S. Weather Bur. Res. Pap. 38, 21 p., illus.

Development of improved methods for estimating annual lake evaporation from pan observations and related meteorological data has been the primary objective of Weather Bureau evaporation studies. The authors show that use of the customary 0.7 coefficient for converting class *A* pan evaporation to lake evaporation can lead to appreciable error unless the effects of advected energy into the lake and heat transfer through the pan are taken into consideration. Techniques are derived to adjust for these effects, and computations of evaporation are made for six reservoirs for which estimates from water budget computations are also available.

Another objective of the Weather Bureau evaporation studies has been the development of a universally applicable relation for computing pan evaporation from meteorological data. A relation of this type has considerable application for estimating the winter season evaporation records, which are generally missing in most part of the United States, and for computing pan evaporation at first-order Weather Bureau stations for strengthening the areal coverage of the network of class *A* evaporation pans. Computations are made from the pan evaporation relation for 22 stations well distributed over the United States, including one Alaskan station. The results indicate that the relation is universally applicable.—From auth. abstr.

Compiler's Note—To simplify the computation, nomographs are presented. These nomographs are also included in Cruff and Thompson (1967, 505).

LAMOREUX, WALLACE W. 379

1962. Modern evaporation formulae adapted to computer use. Mon. Weather Rev. 90(1): 26–28, illus.

Several graphical solutions for computing pan and lake evaporation have been published, but because of the advantages of using a highspeed digital computer in processing masses of data, the graphical representations by Kohler et al. [1955, 378] are reduced to mathematical expressions adaptable to computer use and in terms of readily available input data.—Auth. abstr.

LANE, ROBERT K. 380

1964. Estimating evaporation from insolation. Amer. Soc. Civil Eng. Proc., J. Hydraul. Div. 90(HY5): 33–41.

Data on pan evaporation, E, and solar radiation, Q_s, from several sites in the Western United States were used to correlate the ratio E/Q_s with air temperature, T_a. The resulting prediction equation was tested with other pan evaporation and lake evaporation data. It was found that the equation was useful in predicting monthly values of pan evaporation and annual totals of lake evaporation.—Auth. synop.

ROHWER, CARL 381

1931. Evaporation from free water surfaces. U. S. Dep. Agr. Tech. Bull. 271, 96 p.

A comprehensive review of evaporation processes and research studies is presented.

ROHWER, CARL, FOLLANSBEE, ROBERT, SCOBEY, FRED C., AND OTHERS 382

1933. Evaporation from water surfaces. A symposium. Amer. Soc. Civil Eng. Proc. 59(2): 221–268, illus.

Both pan evaporation and lake surface evaporation are discussed in detail with tables of data.

SLEIGHT, R. B. 383

1917. Evaporation from the surface of water and riverbed materials. J. Agr. Res. 10(5): 209–261, illus.

U. S. GEOLOGICAL SURVEY 384

1954. Water loss investigations: Lake Hefner studies, technical report. U. S. Geol. Surv. Prof. Pap. 269, 158 p.

Relations of open water evaporation and meteorological factors are discussed in great detail.

WILLIAMS, G. P. 385

1961. Evaporation from water, snow and ice. *In* Symposium on Evaporation, Toronto, Canada, 1961. Canada Dep. N. Aff. and Nat. Resour., Water Resour. Br., Hydrol. Symp. Proc. [Ottawa] 2: 31–47.

The basic theoretical differences between evaporation from snow, ice, and water surfaces are outlined. Some estimated energy budget analyses are made to show the order of magnitude of evaporation rates from these surfaces under Canadian conditions. Some measurements of evaporation from snow and water surfaces made in Canada are presented to confirm the theoretical considerations.—Auth. synop.

YOUNG, ARTHUR A. 386

1947. Evaporation from water surfaces in California: summary of pan records and coefficients, 1881 to 1946. Calif. Dep. Public Works Div. Water Resour. Bull. 54, 68 p., illus.

This publication presents a description of methods and apparatus used in recording evaporation, recommendations for the conduct of future ascertainments, and a summarization of the records now available.—From auth. foreword.

YOUNG, ARTHUR A. 387

1948. Evaporation from water surfaces in California—basic data. Calif. Dep. Public Works Div. Water Resour. Bull 54-A, 205 p.

This report is a comprehensive presentation of available data relating to evaporation from water surfaces in California.

See also 5, 18, 456.

Soil Surfaces

CONAWAY, JACK, AND VAN BAVEL, C. H. M. 388

1967. Evaporation from a wet soil surface calculated from radiometrically determined surface temperature. J. Appl. Meteorol. 6(4): 650–655, illus.

The temperature of a naturally exposed, bare wet soil surface was measured with a narrow bandpass infrared radiation thermometer. Corrections were made for actual sky radiance and for surface emittance, determined in the field. When the data were used in calculating evaporation rates with a Dalton-type equation containing a log-law wind function (drag coefficient × windspeed), excellent agreement was found with lysimeter values on both an hourly and daily basis. The results demonstrate the feasibility of surface temperature measurements and support the validity of the log law for describing transfer in the surface layer.—From auth. abstr.

GARDNER, H. R., AND HANKS, R. J. 389

1966. Evaluation of the evaporation zone in soil by measurement of heat flux. Soil Sci. Soc. Amer. Proc. 30(4): 425–428, illus.

Heat-flux plates were employed to measure the movement of heat within a soil column during the process of water evaporation. The movement of

the zone of evaporation was followed for a bare soil column with and without a surface treatment of hexadecanol. Under these conditions the evaporation zone was approximately 1 cm. thick, and equal rates of evaporation were found for the check and hexadecanol treatments when the zones were at the same depth after the treated zone had been passed. Diurnal fluctuation of applied heat energy slowed the evaporation process, but the evaporation zone movement was still evident.—Auth. abstr.

HANKS, R. J., AND GARDNER, H. R. 390

1965. Influence of different diffusivity-water content relations on evaporation of water soil. Soil Sci. Soc. Amer. Proc. 29(5): 495–498, illus.

Estimates of the influence of variations in the diffusivity-water content relation on evaporation showed that, where the diffusivity was changed at high water contents, evaporation was changed accordingly. However, variations in the $D(\theta)$ relation at lower water contents showed little influence on cumulative evaporation.—From auth. abstr.

HEMBREE, G. DANIEL 391

1958. Effect of the state of the ground on the local heat balance. Mon. Weather Rev. 86(5): 171–176, illus.

The heat absorbed by the air during the diurnal temperature rise is computed for Oklahoma City, Okla. Insolation measurements are recorded for each day, and the energy that is not used in raising the temperature is assumed to represent an empirical integration of the other terms of the local energy balance. With this empirical value taken to be the sum of energy losses, computations are made to show the ratio of the energy loss to the total insolation. These ratios of energy loss are correlated to the observed states of the ground. The computations are made for 141 days taken at random during one year. Eight ground states are used in the analysis and significance tests. The results show that the state of the ground affects the energy balance to such an extent that errors of 4° F. or more in maximum temperature forecasts may be due entirely to the effect of the state of the ground.—Auth. abstr.

KEEN, B. A. 392

1941. The evaporation of water from soil. J. Agr. Sci. [London] 6(4): 456–475.

PENMAN, H. L. 393

1941. Laboratory experiments on evaporation from fallow soil. J. Agr. Sci. [London] 31(4): 454–465.

PENMAN, H. L. 394

1946. Some aspects of evaporation in nature. Roy. Coll. Sci. J. [London] 16: 117–129.

In the Rothamsted clay soil, there is little or no water movement from a water table lying at 3 or 4 feet below the surface, and for the coarse sand the limiting depth is about 14 inches. Water tables below these limiting depths (i.e., measured from the surface of bare soil or from the lower limits of plant roots in a cropped soil) will thus make no significant contribution to the soil as a source. Water movement in soil with a slight moisture deficit is extremely slow. As the deficit increases, the reluctance to move increases enormously.

PENMAN, H. L., AND SCHOFIELD, R. K. 395

1941. Drainage and evaporation from fallow soil at Rothamsted. J. Agr. Sci. [London] 31(1): 74–109.

In winter the soil at Rothamsted, England, does not dry at the surface. Winter evaporation is, therefore, much the same as would be obtained from a water surface, and extra rainfall does not affect it.

In summer the surface remains moist only a short time after rain has fallen; the air gradient is then much steeper than in winter. The rest of the time the surface is drier and there is also a vapor pressure gradient in the soil. Hence, (1) there is more rapid evaporation while the surface is wet, (2) the total amount of evaporation is dependent upon both total rainfall and its distribution in time, (3) the later stages of evaporation are more dependent upon soil conditions than on air conditions, and (4) the total evaporation is much less than from open water.—From auth. sum.

VEIHMEYER, F. J. 396

1938. Evaporation from soils and transpiration. Amer. Geophys. Union Trans. 19(2): 612–619.

Since the motion of water at moisture contents lower than field capacity is slow, it would seem that the rate of movement to the surface and, hence, the rate of evaporation loss would be small. The experiments referred to in this paper showed that the loss of moisture by direct evaporation from the surface of the soil (clay loam) is largely confined to a shallow surface layer, about 8 inches deep. Furthermore, the evaporation loss has been shown to be very small compared to the amount of water taken from the soil, as transpired by plants.—From auth. sum.

WAGGONER, PAUL E., AND REIFSNYDER, W. E. 397

1961. Difference between net radiation and water use caused by radiation from the soil surface. Soil Sci. 91(4): 246–250, illus.

See also 18.

PLANT PROCESSES INFLUENCING WATER LOSSES

Absorption and Translocation

General

COWAN, I. R. 398

1965. Transport of water in the soil-plant-atmosphere system. J. Appl. Ecol. [Oxford] 2(1): 221–239.

Water movement in response to gradients of water potential in the soil-plant-atmosphere catena is considered. An approximate solution is presented of the differential equation describing soil moisture flow towards a plant root which is absorbing water at a periodically varying rate. This is combined with hypothetical plant characteristics to form a model of the hydraulic behaviour of a crop. The characteristics specified are the depth of penetration of roots into the soil, the density of rooting (length of root per $cm.^3$ of soil volume), the internal resistance of the crop to the flow of water, and the critical value of leaf water potential which is associated with stomatal closure.—From auth. sum.

GARDNER, W. R. 399

1961. Factors governing the pattern of water utilization in a plant root zone. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 93–97.

The rate of uptake of water by a plant from a soil profile is seldom uniform with depth. Immediately after a wetting of the soil, the plant generally obtains the greater part of its water from the shallower soil layers. These layers thus tend to dry more rapidly than the deeper layers. Because of the relatively low conductivity of unsaturated soil, water does not move rapidly enough throughout the root zone to maintain the water content uniform with depth. As the water content of the shallow layers continues to decrease, the rate of water utilization from these layers tends to decrease and that from

the lower layers tends to increase, so that as time goes on the plant begins to draw proportionately more and more of its water from the lower depths. The region of greatest initial rate of water use generally coincides with the region with the greatest concentration of roots.—From auth. introd.

KOZLOWSKI, THEODORE T. 400

1955. Water metabolism in plants. Harper & Row, N. Y. 227 p.

This book deals with important aspects of water metabolism in plants at the cellular and whole-plant level. It is concerned with evaluation of critical problems relating to the water economy of plants. Attention is focused on xerophytism, water relations of cells, uptake and translocation of water, water loss by plants, and effects of water stress on various physiological processes and growth. In pointing up important areas which need further research, the book attempts throughout to emphasize the dynamic nature of water in a soil-plant-air continuum. It is interdisciplinary in scope.—From auth. preface.

KOZLOWSKI, THEODORE T. 401

1961. The movement of water in trees. Forest Sci. 7(2): 177–192.

Upward movement, internal redistribution, and downward movement of water in trees are reviewed. The vital, root pressure and cohesion of water theories of sap accent are characterized. Recently cited objections to the cohesion theory include the impossibility of maintaining tensions in the presence of air in stems, inadequacy of tensile strength of water, failure of stem pressures to increase proportionally with height, and inadequacy of evidence for existence of continuous water columns. These objections are evaluated.

Critical research of the last decade has provided the cohesion theory with considerable reinforcement, but some criticisms of the theory appear to be valid. Evidence for internal redistribution of water in trees is presented.—From auth. sum.

KRAMER, PAUL J. 402

1945. Absorption of water by plants. Bot. Rev. 11(6): 310–355.

This paper is concerned primarily with the nature and origin of the forces bringing about movement of water from soil or other media surrounding roots into the conducting elements of the xylem and with those internal and external factors which affect the rate of such movement.

Absorption of water is not an independent process, but is closely related to other processes included in the domain of plant-water relations. The rate of water intake is markedly affected by the rate of transpiration and by the extent and condition of the root systems. It is also affected by such environmental factors as the available moisture content of the soil, soil temperature, soil aeration, and to a lesser extent, the kind and concentration of ions in the soil.—From auth. introd.

KRAMER, PAUL J. 403

1963. Water stress and plant growth. Agron. J. 55(1): 31–35.

RIJTEMA, P. E. 404

1961. Evapotranspiration in relation to suction and capillary conductivity. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 99–106.

Water transport through plants from the soil surface to the intercellular spaces in the leaves requires a certain potential gradient, proportional to the flow velocity in the plant. Little is yet known about flow impedances in shoots. It is assumed, however, that the limiting factor is the aperture of the stomata. The control of evapotranspiration by the stomata of plants depends upon climatological, plant-physiological, and soil-physical conditions. For

practical purposes, reduction of evapotranspiration in relation to potential may be approached empirically by measuring soil-moisture tension and capillary conductivity just below the effective root zone.—From auth. sum.

SLATYER, R. O. 405

1960. Absorption of water by plants. Bot. Rev. 26(3): 331–392.

This paper is a thorough review of knowledge of the processes involved in water movement into, through, and out of plants. An extensive literature list is included.

See also 3, 6, 15.

Sapflow

BAKER, H., AND JAMES, W. O. 406

1933. The behavior of dyes in the transpiration stream of sycamore. New Phytol. [London] 32: 245–260.

The transpiration stream is represented as passing up the stem in a multitude of fine branching and rejoining channels formed by single or grouped vessels threading their way through a nonconducting matrix. This study observed the passage of acid fuchsin and methylene-blue solutions through the wood of young sycamore stems under a variety of circumstances.

BLOODWORTH, M. E., PAGE, J. B., AND COWLEY, W. R. 407

1955. A thermoelectric method for determining the rate of water movement in plants. Soil Sci. Soc. Amer. Proc. 19(4): 411–414.

Data show that the method described in this paper is well adapted for indicating the effects of microclimate, soil moisture availability, and soil aeration upon the rate of water uptake and movement within intact plants. In addition, it has other uses which will be of interest to both the soil scientist and plant physiologist.—From auth. abstr.

CLOSS, R. L. 408

1958. The heat-pulse method for measuring rate of sap flow in a plant stem. N. Zealand J. Sci. [Wellington] 1(2): 281–288.

The heat-pulse method for measuring sap flow with the use of two thermocouples appears to work satisfactorily for both an excised poplar twig and a growing plant. The method of measurement and the calculation of the flow are simple; they can be carried out in a few minutes. The plant is not damaged in any way by the measurement.—From auth. sum.

DAUM, C. R. 409

1967. A method for determining water transport in trees. Ecology 48(3): 425–430.

A new form of heat-flow analysis was developed [in Colorado] to measure water transport in tree trunks. The application of the energy budget required the installation of heat-flow plates and thermocouples under the bark to measure the natural heat exchange between the water-conducting layer of xylem and the adjacent parts of the tree. The equipment was installed on two large branches of an ash tree and on the main trunk below. Over an extended period of time, the sum of the flow through the two branches was equal to that through the main trunk, but early in the morning water loss was so high from the branch on the west side of the tree that water must have moved to it from the protected branch on the east. Immediately following sunrise, water loss from the east side was greater. During rain there was reversed transport, indicating that water was absorbed through the leaves. This method permits practically instantaneous measurement of transpiration losses from large trees with no disturbance of the environment of the crown.—Auth. abstr.

GALE, J., AND POLJAKOFF-MAYBER, A. 410

1964. Effect of soil moisture stress on the correlation between heat pulse velocity and transpiration. Plant and Cell Physiol. [Tokyo] 5: 447–455.

Heat pulse velocity in the stem of pine and sour orange seedlings, measured by the heat pulse method, was correlated with transpiration, measured by determining the humidity of air passed over the plants. This correlation was used to calculate transpiration under natural conditions, when heat pulse velocity only was measured.

From the data obtained, it is concluded that transpiration can be reliably calculated from measurements of heat pulse velocity only if the calibration curve relating transpiration to heat pulse velocity is determined shortly beforehand under similar conditions of soil moisture and potential evapotranspiration. Even so, only total daily transpiration can be estimated by this method. Hourly figures of transpiration are unreliable, especially under conditions conducive to low water potential in the plant.—From auth. abstr.

LADEFOGED, KJELD 411

1963. Transpiration of forest trees in closed stands. Physiol. Plant. [Copenhagen] 16: 378–414.

This paper considers studies on the transpiration of eight forest tree species. The primary aim was to investigate the variation in transpiration rates for trees in closed stands and to determine its relation to tree type, size and shape of the crowns, and weather conditions. The measurements reported in the paper were carried out during the summer months of 1954 and 1955; some few measurements were made in the spring of 1956.—From auth. introd.

MARSHALL, D. C. 412

1958. Measurement of sap flow in conifers by heat transport. Plant Physiol. 33(6): 385–396, illus.

In this study, apparatus incorporating a thermistor to measure temperature rises of less than 0.5° F is used to measure the volume rate of sap flow through an area of a few centimeters in the xylem of a conifer.

The experimental method gives a measure of both heat conduction and convection (heat pulse velocity) from the temperature-time curve of a single heat pulse. If only relative sap flow rates are required, the heat pulse velocity is an adequate measure; the only injury to the tree consists in drilling two fine holes. If, however, the actual sap flux in cubic centimeters per square centimeter per hour is desired, a sample of the sapwood must be removed to measure its basic density and moisture content.—From auth. sum.

MARSHALL, D. C. 413

1962. Sap flow analysis charts. N. Zealand J. Sci. [Wellington] 5(4): 521–530.

This paper contains analysis charts enabling heat-pulse velocity and diffusivity to be found by a simple graphical procedure. Previously the complexity of a formula associated with the author's method of measuring sap flow and diffusivity in conifers by heat transport was a disadvantage in the formula's use.

ROBINSON, T. W., AND DONALDSON, D. 414

1967. Pontacyl brilliant pink as a tracer dye in the movement of water in phreatophytes. Water Resour. Res. 3(1): 203–211, illus.

In connection with evapotranspiration studies, pontacyl brilliant pink (a fluorescent dye) was used to trace the movement of water in two species of woody phreatophytes, willow and wildrose. The dye was introduced into water surrounding the plant roots on August 4, 1964. Thereafter, leaf samples were collected periodically until the end of the growing season in October. Fluorometric measurements showed the presence of the dye in the

leaves. Dye was also found in samples of roots and stems and in transpired water collected in plastic bags. Dye concentration was greatest in the upper part of the stems. As a tracer the dye offers a rapid method for studying the source, movement, and disposal of water used by phreatophytes. The method is rapid and inexpensive, and the laboratory determination is not difficult. The fluorometric determinations were made with a GK Turner fluorometer Model 111, which has a sensitivity of 1 ppb.—Auth abstr.

SKAU, C. M., AND SWANSON, R. H. 415

1963. An improved heat pulse velocity meter as an indicator of sap speed and transpiration. J. Geophys. Res. 68(16): 4743–4749.

Modifications are shown of Swanson's original instrument for determining heat pulse velocity in woody plants. These modifications stabilize the instrument from −50° to +80° C. and allow simultaneous multipoint sampling. Laboratory experiments are reported which demonstrate that heat pulse velocity is closely related to volume of water forced through stem sections. Field experiments with juniper trees show that (1) on clear days the heat pulse velocity increases rapidly from sunrise to midmorning and remains high until sunset; low rates prevail at night; (2) leaf wetting produces an immediate decrease in heat pulse velocity; rates remain low while leaves are wet, then increase rapidly when leaves dry; (3) within 24 hours after dry soil is irrigated, heat pulse velocity increases two to five times; and (4) natural soil drying, even with high air temperatures, causes a decrease in heat pulse velocity. These results tend to verify what has been heretofore mainly conjecture based on the measurement of external variables surrounding a tree.—Auth. abstr.

SWANSON, ROBERT H. 416

1962. An instrument for detecting sap movement in woody plants. U. S. Dep. Agr. Forest Serv. Rocky Mt. Forest and Range Exp. Sta. Sta. Pap. 68, 16 p., illus.

This paper describes a portable instrument for detecting sap movement—a timer, so to speak—that enables one to obtain data for solving an equation relating time and heat pulse velocity. The instrument can be used on any stem, branch, or root larger than one-half inch in diameter.—From auth. abstr.

SWANSON, ROBERT H. 417

1967. Improving tree transpiration estimates based on heat pulse velocity measurements. *In* XIV IUFRO-Kongress, München, 1967. Int. Union Forest. Res. Organ. Papers I (Sect. 01-02-11): 252–263, illus.

To estimate tree transpiration from heat pulse velocity, one must know the mean sap flux and the area of the sap stream in cross section. Sap flux is computed from heat pulse velocity, wood moisture content, density, and specific heat. This paper shows that the cross-sectional area within which sap ascends, the moisture content, and density of the conducting wood are not constant. Changes in these values must be considered before comparative transpiration estimates from heat pulse velocity are made.

The data used in this paper were taken from two tree species common to the Rocky Mountains of Colorado, lodgepole pine (*Pinus contorta* Dougl.) and Engelmann spruce (*Picea engelmanni* Parry).—From auth. introd.

WENDT, C. W., RUNKLES, J. R., AND HAAS, R. H. 418

1967. The measurement of water loss by mesquite (*Prosopis glandulosa* var. *glandulosa* Torr.) using the thermoelectric method. Soil Sci. Soc. Amer. Proc. 31(2): 161–164.

The quantitative aspects of the thermoelectric method of measuring water loss were investigated in a controlled environment chamber. A high degree of correlation for mesquite stems less than 10 mm. in diameter ($r = 0.97$) was obtained between water transpired and the product of the cross-sec-

tional area of the stem and the relative sap velocity. As the size of trees increased, the correlation decreased because of variations in relative sap velocities around the circumference of larger trees. Although the correlation coefficient was high for trees less than 10 mm. in diameter, the coefficient of variation was 15.6 percent, which was probably due to the variation in the moisture content of the plants.—From auth. abstr.

See also 6, 15, 240, 425.

Plant-Water Stress

BOYER, J. S. 419

1967. Leaf water potentials measured with a pressure chamber. Plant Physiol. 42(1): 133–137.

Leaf water potentials were estimated from the sum of the balancing pressure, measured with a pressure chamber, and the osmotic potential of the xylem sap in leafy shoots or leaves. Leaf water potentials in yew, rhododendron, and sunflower were compared with those measured with a thermocouple psychrometer known to indicate accurate values of leaf water potential. Determinations were within ±2 bars of the psychrometer measurements with sunflower and yew. With rhododendron, water potentials, measured with a pressure chamber, plus xylem sap were 2.5 bars less negative to 4 bars more negative than psychrometer measurements.

The discrepancies in the rhododendron measurements could be attributed, at least in part, to the filling of tissues other than xylem with xylem sap during measurements with the pressure chamber. It was concluded that, although stem characteristics may affect the measurements, pressure-chamber determinations were sufficiently close to psychrometer measurements that the pressure chamber may be used for relative measurements of leaf water potentials, especially in sunflower and yew. For accurate determinations of leaf water potential, however, pressure-chamber measurements must be calibrated with a thermocouple psychrometer.—From auth. sum.

KAUFMANN, MERRILL R. 420

1968. Evaluation of the pressure chamber technique for estimating plant water potential of forest tree species. Forest Sci. 14(4): 369–374.

The pressure-chamber method for rapid field or laboratory estimation of plant water stress was evaluated; the thermocouple psychrometer technique was used. The psychrometer is believed to provide the most accurate measurements of leaf water potential available, when certain precautions are taken. The pressure chamber method estimates xylem pressure potential.

Comparisons were made by bringing seedlings or large branches into the laboratory and making measurements on leaf samples in the psychrometer and on single leaves or stem tips in the pressure chamber. Most comparisons on *Pinus taeda* L., *P. strobus* L., *Picea engelmannii* Parry, and *Liriodendron tulipifera* L. agreed within 5 bars. With *Quercus ruba* L. and *Q. alba* L., however, the observed pressure potentials were as much as 16 bars lower than leaf water potential. These discrepancies prevent using the values obtained by the pressure chamber technique as direct estimates of leaf water potential for the species studied. The most appropriate way to use the pressure chamber method in evaluating plant-water stress is to first determine calibration curves for each species, relating the estimate of xylem pressure potential to known leaf water potential.—Auth. abstr.

KRAMER, P. J., AND BRIX, H. 421

1965. Measurement of water stress in plants. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 343–351.

The most important aspect of plant-water relations is the internal water balance or degree of water stress, because this controls the physiological

and biochemical processes and conditions which determine the quantity and quality of plant growth.

The need for a method of evaluating the water balance of plants has been appreciated by ecologists and physiologists for many decades, but there has been no general acceptance of any of the many methods proposed. Perhaps investigators have been deterred from making measurements because of the difficulty of deciding which one of the multiplicity of methods to use. The most important methods are described briefly in this paper.—From auth. introd.

LAMBERT, JERRY R., AND VAN SCHILFGAARDE, JAN 422

1965. A method of determining the water potential of intact plants. Soil Sci. 100(1): 1–9, illus.

Water contents of leaves left intact on the plant were measured with a thermocouple psychrometer.

SCHOLANDER, P. F., BRADSTREET, EDDA D., HAMMEL, H. T., AND HEMMINGSEN, E. A. 423

1966. Sap concentrations in halophytes and some other plants. Plant Physiol. 41(3): 529–532, illus.

The pressure-chamber method was used, and sketches of the equipment are included in this paper.

SCHOLANDER, P. F., HAMMEL, H. T., BRADSTREET, EDDA D., AND HEMMINGSEN, E. A. 424

1965. Sap pressure in vascular plants. Science 148(3668): 339–346.

A pressure-chamber method is described which permits measurement of sap pressure in the xylem of vascular plants. As long predicted, sap pressures during transpiration are normally negative, ranging from −4 to −5 atmospheres in a damp forest to −80 atmospheres in the desert. Mangroves and other halophytes maintain at all times a sap pressure of −35 to −60 atmospheres. Diurnal cycles of 10 to 20 atmospheres are common. In tall conifers, there is a hydrostatic pressure gradient that closely corresponds to the height and seems surprisingly little influenced by the intensity of transpiration.—From auth. sum.

SWANSON, ROBERT H. 425

1970. The tree as a dynamic system in forest-water resource research. *In* Third Forest Microclimate Symposium Proc., Seebe, Alberta, Sept. 23–26, 1969. Canadian Forestry Service [Calgary, Canada]. p. 34–39.

When is a tree reacting solely to its environment and when is it not? This question cannot be answered by environmental measurements alone. The tree itself should be used as an indicator.

Water content may or may not show daily or seasonal fluctuations. The fact that the water columns within the xylem are often under tension makes doubtful some of the past work on this subject. New methods—either taking such tension into account or capable of being applied nondestructively external to the tree—are needed in order to answer this question. It appears that hammered increment cores are a better sample of water content than those taken with a borer; however, the former may still not yield the correct value.

Transpiration cannot be considered to proceed at the potential rate simply because the climatic parameters are favorable. There is apparently an upper limit to how much stress a tree can be subjected to before it desiccates owing to nonavailability of water. In the example shown of Aleppo pine, this level was approximately 35 atmospheres. Species difference may exist. Tension measurements in mesquite of 80 to 100 atmospheres are not uncommon. The author has not seen tensions higher than 16 atmospheres in lodgepole pine. (However neither one has been subjected to the harsh

treatment the Aleppo pine received.) Suffice it to say, internal water tension is an easily measured parameter that should be included as an indicator of the plant's reaction to the environment whenever evapotranspiration is estimated by mass or energy-exchange relationships.—From auth. discuss. and conclusions.

SWANSON, ROBERT H., AND LEE, RICHARD 426

1966. Measurement of water movement from and through shrubs and trees. J. Forest. 64: 187–190.

Three techniques whereby plant transpiration can be estimated or detected are presented in this paper. These are: (1) The tent technique—evapotranspiration measured by enclosing a plant in a flexible greenhouse and measuring the rate of vapor production, (2) the quickweigh method—excised portions of plants are weighed to determine the rate of water loss, and (3) the sap movement method—sap velocity is measured and related to various parameters affecting the tree's rate of transpiration. Results from each of the three methods are presented, along with a brief discussion of each method's advantages and disadvantages when compared with the other two.—From auth. abstr.

VISSER, W. C. 427

1965. The moisture consumption of plants described as a hydrologic phenomenon. *In* Water Stress in Plants. Czech. Acad. Sci. Symp. Proc., Prague, Sept. 30–Oct. 4, 1963. Dr. W. Junk Pub. [The Hague], p. 257–265, illus.

Evapotranspiration is considered to depend on three factors: The capillary movement of water through the unsaturated soil to the root surface, the transmissibility of the stomata, and the evaporative capacity of the atmosphere.

It has proved possible to evolve a quantitative description of the flow of moisture through the soil and the plant. This flow is a function of the availability of the soil moisture and the consumptive needs of the plant, depending on the potential evaporation due to radiation.—From auth. introd.

WARING, RICHARD H., AND CLEARY, BRIAN D. 428

1967. Plant moisture stress: evaluation by pressure bomb. Science 155(3767): 1248, 1253–1254.

The recently developed technique for determining the water stress of a plant by measuring the pressure necessary to force water back to the cut surface of a severed twig is adaptable to both field and laboratory experiments. An efficient portable system has been designed. Sampling variation within and among Douglas-fir trees varies from less than ± 1 atmosphere under low stress conditions to ± 10 atmospheres under high stress conditions. Differences in stresses between completely shaded and fully exposed trees may be as much as 6 atmospheres.—From auth. abstr.

See also 4, 475.

Transpiration

ARKLEY, RODNEY J. 429

1963. Relationships between plant growth and transpiration. Hilgardia 34(13): 559–584, illus.

The purpose of this paper was to establish principles for determining the quantitative relationships between climate and plant growth. It is known that the amount of dry matter produced by any plant and the water it transpires are proportional and that this relation is constant for each plant species or variety under a given set of growing conditions. Dry-matter production was plotted against water use—separately for each level of soil fertility—and equations were formulated to show the relationships under

different conditions; published experimental data were used. The analysis showed that a correction based on atmospheric humidity accounts for about 90 percent of the variation in the ratio of dry-matter production to transpiration when soil fertility is constant and that a correction for soil fertility accounts for about 75 percent of the variation when climate is constant.

These principles are applied to the interpretation of field experiments dealing with water use by plants. They may be useful in determining the most advantageous allocation of limited amounts of irrigation water in different climatic regions and in many other ways.—From auth. abstr.

CLEMENTS, F. E., AND MARTIN, E. V. 430

1934. Effects of soil temperature on transpiration in *Helianthus annuus*. Plant Physiol. 9(3): 619–630, illus.

The effect of soil temperature in the range of 34° to 100° F. on transpiration of *Helianthus annuus* phytometers 6 to 8 weeks old was measured by using five sets of four or nine plants each, placed simultaneously in water baths of different temperatures. It was found that transpiration varies very little with soil temperatures between 55° F. and 100° F. but drops rapidly below 55° F., was reduced to half at 38° F., and approached zero at 32° F.—From auth. sum.

CLEMENTS, HARRY F. 431

1934. Significance of transpiration. Plant Physiol. 9(1): 165–171.

Data are presented on the following topics: Transpiration as it reduces leaf temperatures; transpiration as it buffers leaf temperature; transpiration as it enables rapid movement and distribution of inorganic solutes; transpiration as it aids photosynthesis; transpiration as it makes possible rapid tall growth of plants; and transpiration as a fact.

EHLIG, C. F., AND GARDNER, W. R. 432

1964. Relationship between transpiration and the internal water relations of plants. Agron. J. 56(2): 127–130, illus.

Below a characteristic diffusion pressure deficit value for each plant, the transpiration rate was proportional to the potential transpiration. Above this value, the transpiration rate tended to decrease, rapidly at first and then more slowly, with increasing diffusion pressure deficit. The relative rate loss from initially turgid detached leaves decreased very markedly with decreasing water content at a water content of about 90 percent of that at full turgor and corresponding to a diffusion pressure deficit by about 10 to 15 bars.—Auth. synop.

FRANCO, C. M., AND MAGALHAES, A. C. 433

1965. Techniques for the measurement of transpiration of individual plants. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 211–224.

The earliest measurement of plant transpiration seems to have been made by Hales, who measured transpiration of several potted plants by weighing the containers. Numerous methods of measuring transpiration have been published. The three methods most widely used nowadays are discussed: The potted plant weighing method, the gasometric method, and the rapid weighing method.

GARDNER, W. R., AND EHLIG, C. F. 434

1963. The influence of soil water on transpiration by plants. J. Geophys. Res. 68(20): 5719–5724, illus.

A relationship between transpiration and soil suction and soil-water content has been derived [at the Salinity Laboratory of the U. S. Agricultural Research Service, Riverside, Calif.]. Good agreement between the theory and results of laboratory experiments was obtained. The results suggest that

once plants wilt, the transpiration rate should be roughly proportional to the available water content of the soil. The lower limit of water available for transpiration occurs at a suction well above 15 bars.—Auth. abstr.

GATES, DAVID M. 435

1964. Leaf temperature and transpiration. Agron. J. 56(3): 273–277.

The mechanisms which contribute to the energy exchange for a leaf are described, and a graphical solution to the heat transfer equation for a leaf is presented. The importance of transpiration for cooling a leaf is shown in quantitative form. The complete energy budget for a leaf of *Quercus macrocarpa* was observed at various times of day; radiation, convection, transpiration, and leaf temperature were included. It is shown that good agreement is realized between the energy absorbed by the leaf and the energy consumed by dissipative mechanisms.—From auth. synop.

HORTON, ROBERT E. 436

1934. Water losses in high latitudes and at high elevations. Amer. Geophys. Union Trans. 15(2): 351–379, illus.

The author considers three kinds of water losses: (1) Rainfall interception, (2) transpiration by vegetation, and (3) evaporation from the soil.

Transpiration, which is the principal type of water loss in tropical and temperate climates, becomes of decreasing importance in high latitudes and at high elevations, as vegetation takes on more sparse, stunted, alpine, or semi-xerophytic characteristics, until, to the north of or above the snow-line, transpiration is negligible and the only source of water loss is direct evaporation from the snow surfaces.

KNOERR, K. R., AND GAY, L. W. 437

1965. Tree leaf energy balance. Ecology 46(1 & 2): 17–24.

Detached leaves of three tree species, *Quercus velutina, Magnolia grandiflora,* and *Prunus caroliniana,* were exposed in transpiring and nontranspiring situations under high radiation intensities to a range in wind velocities. Convective heat losses from these leaves were determined as a residual in the energy balance equation, with all other energy exchange components being measured or known. The leaves responded to their external environment in accordance with accepted heat transfer theory. Leaf-air temperature differences were maximum for nontranspiring leaves in still air and minimum for transpiring leaves exposed to high wind velocities.

Convective heat transfer coefficients, calculated from the measurements of convection, were compared with those determined from heat transfer theory. The forced convection coefficients agreed closely with those predicted by theory. The free convection coefficients, however, were close to the theoretical values only for the larger leaves. They increased to about twice the predicted values as leaf size decreased. Reasons for this difference are discussed.

The ratios between convection and latent heat exchange (Bowen ratios) for the individual leaves were different from published values for whole forest stands. These differences are considered in discussing the relative role of individual heat transfer processes in various portions of the tree crown.—Auth. abstr.

KONSTANTINOV, A. R., GOISA, N. I., AND OLEINIK, R. N. 438

1969. Relation between transpiration and the spectral composition of radiation. (Svyaz' transpiratsii so spektral'nym sostavom oblucheniya. Ukr. Nauch. Issled. Gidrometeorol. Inst. Tr. [Kiev] 1964. 41: 126–134.) Trans. from the Russian, Israel Program for Sci. Trans. Cat. No. 5255 (TT68-50435) Jerusalem, Israel.

This paper describes the results of experimental studies on the relation between the radiation spectrum and the intensity of transpiration of dry

steppe vegetation as compared to vegetation growing in a region receiving frequent rain.

KOZLOWSKI, THEODORE T. 439

1943. Transpiration rates of some forest tree species during the dormant season. Plant Physiol. 18: 252–260.

This paper reports the results of a comparison of the winter transpiration rates of several deciduous and evergreen tree species. The species were: White oak (*Quercus alba*), yellow-poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), cherry laurel (*Prunus laurocerasus*), eastern white pine (*Pinus strobus*), and loblolly pine (*Pinus taeda*). The investigations were made during the dormant season of 1940-41 in Durham, N. C.

No great difference was observed in foliar transpiration of conifers and stem transpiration of deciduous species on a unit area basis.—From auth. introd. and sum.

KOZLOWSKI, T. T. 440

1949. Light and water in relation to growth and competition of Piedmont Forest tree species. Ecol. Monogr. 19(3): 207–231, illus.

Effects of light intensity and soil moisture on photosynthesis, transpiration, and growth of pine and hardwood seedlings were studied.—From auth. sum.

LIVINGSTON, BURTON E. 441

1938. Influences that affect transpiration from plant leaves. Sigma Xi Quart. 26(2): 88–101, illus.

MILTHORPE, F. L. 442

1961. Plant factors involved in transpiration. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 107–115.

The important plant factors influencing transpiration are the stomatal conductance and the external resistance, which is a function of the degree and structure of the leaf cover (in the field) or the size and arrangement of leaves (in laboratory experiments). Knowledge of these, together with the evaporation potential, is essential to an exact estimation of the transpiration rate. If the stomata are completely closed, the magnitude of the cuticular conductance will appreciably influence the rate of water loss. A much wider knowledge of the variations of these three components in the field is required. Effects arising from the conductances of the cell wall and the substomatal cavities are likely to be extremely small.—Auth sum.

MINCKLER, LEON S. 443

1939. Transpiration of trees and forests. J. Forest. 37(4): 336–339, illus.

The author has studied the transpiration of several important forest trees. It was found that the transpiration in acre-inches of a hypothetical forest ranged from about 5 to 17 for red maple, 1½ to 7 for American elm, and 2 to 8 for northern white pine. Sugar maple and beech each transpired about 3 acre-inches. Attention is called to the fact that water requirement data collected on potted seedlings should not be applied to forest trees growing under natural conditions.—From auth. abstr.

NEWTON, J. D. 444

1925. The relation of the salt concentration of the culture solution to transpiration and root respiration. Sci. Agr. [Ottawa] 5: 318–320.

The experiments reported showed that the rate of plant root respiration, as related to transpiration, is increased when the salt concentration of the

culture solution is increased. It was further shown that the rate of transpiration is decreased when the concentration of the culture solution is increased. It is pointed out that the concentration of the soil solution is one of the factors governing water requirements of crops.—From auth. sum.

OPPENHEIMER, H. R. 445

1953. An experimental study on ecological relationships and water expenses of Mediterranean forest vegetation. Palest. J. Bot. Rehovot Ser. 8(2): 103–124.

The author investigated the transpiration of *Quercus calliprinos, Laurus nobilis, Phillyrea media,* and *Pistacia palaestina* in their natural habitat by rapid weighings on the torsion balance. Transpiration varied with the species, partly because of the degree of stomatal closure characteristic of the shrub.

PENMAN, H. L., AND SCHOFIELD, R. K. 446

1951. Some physical aspects of assimilation and transpiration. Soc. Exp. Biol. Symp. [London] 5: 115–129.

Assimilation and transpiration can be treated as formally identical apart from a change in sign of the concentration gradient. The diffusive flow of carbon dioxide and water vapor is hindered by resistance arising partly outside the leaves and partly in the epidermis.—From auth. sum.

WAISEL, YOAV 447

1960. Ecological studies on *Tamarix aphylla* (L.) Karst. II. The water economy. Phyton [Vicente Lopez, Argentina] 15(1): 19–28.

Various aspects of the water economy of *Tamarix aphylla* were investigated. It was demonstrated by the cut-leaf method that this tree, though exhibiting rather high transpirational values in comparison to other tree species under the same conditions, cannot be considered as wasting water. On the basis of the mean transpiration value obtained—350 mg./g./h.—the carrying capacity of a desert sand dune area was calculated and the maximal density in which *T. aphylla* trees might be planted was arrived at. This density cannot exceed 32 trees per acre, unless the plantation depends on the water reserves of the soil. This was based on the calculations that each kilogram of fresh plant material transpires daily (10 hours of transpiration) about 3.5 liters, or yearly about 1.27 tons of water.

Water absorption by the aerial organs of *T. aphylla* was investigated in a series of experiments in which the twigs were sprayed for various periods with water or salt solutions. The results revealed a considerable absorption of water only under high saturation deficits of the twigs and during very long periods of continuous spraying. Under field conditions, although the twigs of *T. aphylla* became wet almost nightly, only a little water was absorbed by the aerial organs, owing to lower saturation deficits prevailing and to the short duration of moistening. The small amounts absorbed are not sufficient to cover the saturation deficits of the plants, but might have some survival value under the stress of sublethal water deficits.

The amounts of water precipitated by the trees of *T. aphylla* from atmospheric humidity, are quite large and might come into account as an additional water source, especially in regions with frequent humid nights.—From auth. abstr.

WENDT, CHARLES W., HAAS, ROBERT H., AND RUNKLES, J. R. 448

1968. Influence of selected environmental variables on the transpiration rate of mesquite (*Prosopis glandulosa* var. *glandulosa* (Torr.) Cockr.). Agron. J. 60(4): 382–384.

The influence of soil moisture, soil temperature, and vapor pressure deficit on the transpiration rate of mesquite was studied in controlled environment chambers.

Four soil moisture levels were maintained by adding water when the soil moisture contents were 12.9, 15.4, 19.0 and 25.2 percent to increase

moisture content to 39.3 percent. The suction at these moisture contents was 15.0, 6.3, 1.5, 0.5, and 0.1 bar, respectively. There was no significant difference in the transpiration rate between the different soil moisture levels.

The plants were grown at soil temperatures of 13°, 21°, 29° and 38° C. The transpiration rate was highest at 29° C.

As the mean vapor pressure deficit of the atmosphere was increased from 3.5 to 20.9 mm. Hg., it had a diminishing effect on the transpiration rate, indicating that mesquite does not increase its transpiration rate proportionally with increasing vapor pressure deficit.—Auth. abstr.

YAMAOKA, YOSHITO 449

1958. Experimental studies on the relationship between transpiration rate and the meteorological elements. Amer. Geophys. Union Trans. 39(2): 249–265.

An investigation was carried out of transpiration rate as a fundamental datum of water resources; a wind tunnel which can maintain any meteorological condition was used. Various examinations were performed by the potometer method, and the method was found satisfactory in the investigations. The transpiration rate obtained by the potometer agreed within ± 2.4 percent with that of the potted plant. Empirical formulas were obtained from the relation of the transpiration rate to radiation intensity and wind velocity for *Myrica rubra*. Also, the relations of the leaf temperature to transpiration rate and meteorological elements were studied.—From auth. abstr.

YAMAOKA, YOSHITO 450

1958. The total transpiration from a forest. Amer. Geophys. Union Trans. 39(2): 266–272.

The total leaf weight of *Cryptomeria japonica* was found to be proportional to the square of the breast-high diameter. The relations between transpiration rate and the meteorological elements for this species were also investigated, and the empirical formulas necessary for estimating the total transpiration were obtained. Finally, a stand of 740 45-year-old *Cryptomeria japonica* (4,376 sq. m. or about 1.1 acre) was selected; the total leaf weight was estimated at 69 tons and the total transpiration at 1.80 tons/hour at an air temperature of 26.6° C., relative humidity of 80 percent, wind velocity of 3.5 m./sec. and radiation intensity of 1 cal./cm.^{2} min. This value was compared with the water loss from various types of surfaces to show that there was no serious error in the estimate.

The relations between leaf temperature and transpiration rate and meteorological elements were also investigated.—From auth. abstr.

See also 2, 3, 4, 6, 15, 91-133, 243, 436.

EFFECT OF CHEMICALS ON EVAPORATION AND TRANSPIRATION

Evaporation and Evapotranspiration Control by Chemicals

ANDERSON, HENRY W., WEST, ALLAN J., ZIEMER, ROBERT R., AND ADAMS, FRANKLIN R. 451

1963. Evaporative loss from soil, native vegetation, and snow as affected by hexadecanol. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge, Belgium] 62: 7–12.

Only in a bulldozed brush field and with heavy applications of hexadecanol under snow did significant reductions in evapotranspiration occur with application of hexadecanol to natural stands. Marked reductions in evaporation from snow occur with application of hexadecanol to natural stands. Marked

reductions in evaporation from snow occurred when hexadecanol emulsion was applied to the snow surface.—Auth. abstr.

ANGUS, D. E., AND BIELORAI, H. 452

1965. Transpiration reduction by surface films. Aust. J. Agr. Res. 16(2): 107–112, illus.

Exploratory tests of the possibility of reducing plant transpiration by means of surface films are described. Cetyl alcohol reduced transpiration significantly but also caused considerable damage to the plants. Low viscosity silicone oils reduced transpiration by up to about 50 percent and caused only marginal growth abnormalities. Comparison of the present data with other work in which film-forming materials were added to the root medium of plants suggests that foliar application is preferable to root application.—From auth. sum.

ATSATT, P. R., AND BLISS, L. C. 453

1963. Some effects of emulsified hexa-octa decanol on germination, establishment, and growth of Kentucky bluegrass. Agron. J. 55(6): 533–537, illus.

AUBERTIN, G. M., AND GORSLINE, G. W. 454

1964. Effect of fatty alcohol on evaporation and transpiration. Agron. J. 56(1):50–52, illus.

Greenhouse experiments using maize were undertaken during 1961 to investigate the effect of a fatty alcohol mixture on evapotranspiration. Total water usage, evaporation, and plant growth were reduced, but transpiration was reduced only by the first increment of fatty alcohol, because of decreased plant growth, and no further change occurred with additional increments. All treatments required the same amount of transpiration water to produce one gram of oven-dry material. Total water usage per gram of material increased with the additions of alcohol because plant growth was decreased proportionately more than transpiration.

BIELORAI, H., AND ANGUS, D. 455

1959. Transpiration reduction by spraying with low viscosity silicone. Israel Res. Counc. Bull. [Jerusalem] Sect. D Bot. 7D(1): 105–106.

Greenhouse tests were conducted on sunflower plants (*Helianthus annuus*). Cetyl alcohol reduced transpiration, but this reduction was caused by considerable damage and stunting of the plants. The only other substances which had any appreciable effect in reducing transpiration rates were the low viscosity silicones (40 and 50 centistokes). A slight leaf deformation appeared occasionally.

BLOODGOOD, GRANT (Chairman) 456

1959. Water-loss investigations: Lake Hefner, 1958, evaporation reduction investigations. Report by the collaborators. U. S. Dep. Interior and others. 131 p., illus.

Lake Hefner, Okla., was chosen for evaporation research conducted in 1950–51 and for evaporation suppression tests in 1958 primarily because it is one of the few reservoirs in the United States where evaporation can be determined accurately by the water-budget method. In the present study, the actual evaporation from Lake Hefner was determined; of equal importance was the determination of the evaporation that would have occurred if a monomolecular film had not been applied.—From introd.

CRUSE, ROBERT R., AND HARBECK, G. EARL, JR. 457

1960. Evaporation control research, 1955–58. U. S. Geol. Surv. Water-Supply Pap. 1480, 45 p., illus.

One hundred and fifty-two compounds and compositions of matter were

screened as potential evaporation retardants. The homologous straight-chain fatty alkanols are considered the best materials for retardants.

Several methods of application of the alkanols to a reservoir surface were investigated. Although use of wick-type drippers for the application of liquids and use of cage rafts for the application of solids appear to be the most promising methods from an economic standpoint, both methods have serious disadvantages.

Considerable study was made of reducing biochemical oxidation of the evaporation retardants. Copper in several forms was found adequate as a bacteriostatic agent but posed a potential hazard because of its toxicity. Many other bactericides that were tested were also toxic.

Two sets of large-scale field tests have been completed and several others are still in progress. On larger reservoirs, the reduction of evaporation was not more than 20 percent under prevailing conditions and the application procedure used.

Three major practical matters remain to be studied; namely, the effects and action of wind on the monofilm, the effects of biochemical oxidation, and the most effective methods of application. Fundamental matters remaining to be studied include the effects of various impurities; the composition of the best evaporation retardant; the long-range effects of the monofilms on the limnology of the reservoir, including transfer of oxygen and carbon dioxide; toxilogical aspects of all components of any evaporation-retardant composition and toxicology of any composition chosen for large-scale use; and the calorimetry and thermodynamics involved in the mechanism of evaporation and its reduction by a monofilm.—From auth. abstr.

DAVENPORT, DAVID C., HAGAN, ROBERT M., AND MARTIN, PAUL E. 458

1969. Antitranspirants research and its possible application to hydrology. Water Resour. Res. 5(3): 735–743, illus.

Research on antitranspirants may have application in increasing the yield of water from watersheds by reducing transpirational losses from vegetation under certain environmental conditions. There are three broad groups of antitranspirants: (1) Reflecting materials that decrease the heat load on the leaf, (2) film-forming materials that hinder the escape of water vapor from the leaf, and (3) stomata-closing materials that increase stomatal resistance. Antitranspirants are most effective in decreasing transpiration when other resistances in the passage of water to the roots, through the plant, and to the atmosphere are not great; when there is good coverage of the stomatal bearing leaf surfaces (except for reflecting materials); when new foliar growth following treatment is minimal; and when optimum concentration and application rates are used.—Auth. abstr.

FRASIER, GARY W., AND MYERS, LLOYD E. 459

1968. Stable alkanol dispersion to reduce evaporation. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 94(IR 1): 79–89, illus.

Highly stable sol- or gel-type dispersions of long-chain alkanols in water have been prepared and shown to be more effective than powdered alkanol in reducing evaporation from water surfaces. Surfacants used to prepare the dispersions are algicides and bactericides. Dispersion samples have shown no separation or deterioration after 5 years' storage under nonsterile conditions. Concentrated dispersions can be prepared for shipment or storage and can be diluted with water containing up to 1,700 p.p.m. of soluble salts to make stable, low-viscosity dispersion for application with simple drip-type applicators. Film release rates and film pressures from dispersions exceed those from powder. Fifty pounds of powdered alkanol per acre per month reduced evaporation from outdoor tanks by 15 percent under adverse testing conditions. Under the same conditions only 10 pounds of dispersed alkanol per month reduced evaporation by 28 percent.—Auth. abstr.

GALE, J., AND HAGAN, ROBERT M. 460

1966. Plant antitranspirants. Ann. Rev. Plant Phys. 17: 269–282.

In the present state of antitranspirant research, the main practical problem is the development of improved antitranspirants. Longer retention and greater specificity are required for antitranspirants of the stomata-closing type and greater selectivity to gases and vapors for antitranspirants of the film-forming type. With the development of such materials, physiologists must then look at their effects, direct and indirect, on processes such as mineral nutrition and photosynthesis. Measurements should be made under a variety of controlled and well-defined environmental conditions. Such data are a prerequisite to recommendations concerning the suitability of any type of antitranspirant for any specific application.—Auth. conclusion.

GALE, J., ROBERTS, EDWIN B., AND HAGAN, ROBERT M. 461

1967. High alcohols as antitranspirants. Water Resour. Res. 3(2): 437–440.

The use of monomolecular films of high alcohols to reduce evaporation from open water surfaces has stimulated much work on the possibility of applying these materials to plants to reduce transpiration. The results of 17 such investigations indicate that, at concentrations that reduce transpiration, these materials also reduce plant growth. The one study that reported reduction of plant transpiration and increase of growth was repeated, but with negative results. Analysis of the relative resistance of hexadecanol films to flow of carbon dioxide and water vapor and their relation to resistances to flow normally found in plant leaves indicate that these films should reduce photosynthesis more than transpiration. It is concluded that such materials are not suitable as antitranspirants.—Auth. abstr.

ISRAELSON, C. EARL, AND HANSEN, VAUGHN E. 462

1965. Evaporation reduction on large reservoirs. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 91 (IR 1): 93–98.

A brief history is given of current methods of applying monolayer-forming chemicals and of conditions influencing the development of aerial dispensing equipment.—From auth. synop.

KOLP, DON G., KRAUSE, FRANK P., AND LANGE, WILLY 463

1966. Effect of tallow alcohol added to soil on the tension, flow, and evaporation of soil water. Water Resour. Res. 2(2): 213-222, illus.

Tallow alcohol (TA) affects the properties of water in soil by forming compressed monolayer films on the water-filled pores of the soil. Besides directly effecting a small evaporation reduction, the films lower the soil-water tension. This tension-lowering leads to several other effects, including reduction of the flow rate of water through uniform soils and, in layered soils, lowering of the soil-water concentration in the TA-containing layer. The last effect, which leads to self-mulching, accounts for most of the substantial evaporation reduction from soils with TA in the surface layer. This effect also aids the infiltration of water into such soils. The full effects of TA are realized only when it is solvent-dispersed; with powdered TA only partial effects are obtained. Attention is directed to the possible effects on the soil/fatty alcohol/water system of soil micro-organisms growing on fatty alcohol.—Auth. abstr.

LAMER, VICTOR K., AND HEALY, THOMAS W. 464

1965. Evaporation of water: its retardation by monolayers. Science 148(3666): 36–42.

Principles and results of the use of monomolecular films are discussed.

MARSHALL, HUBERT, AND MAKI, T. E. 465

1946. Transpiration of pine seedlings as influenced by foliage coatings. Plant Physiol. 21(1): 95–101, illus.

The water loss from white pine, red pine, and loblolly pine seedlings was determined gravimetrically during exposure to environmental conditions of high temperature and low humidity. With ample conditions of high moisture in the potting medium, seedlings top-dipped in emulsions of lanolin or a commercial paraffin wax transpired, during 4 days of exposure, less than 40 percent as much as untreated seedlings. Regression equations demonstrated that water loss varied directly with the fresh weight of the seedlings within the range of the data.—From auth. sum.

MYERS, LLOYD E. 466

1965. Evaporation retardants: application by means of a water-soluble matrix. Science 148(3666): 70–71.

Evaporation retardants interspersed in a solid or semisolid matrix of water-soluble material allow discrete particles of retardant to be released at a controlled rate as the matrix dissolves. This system permits the continuous application of evaporation retardants to a water surface without the use of mechanical devices.—Auth. abstr.

NEALES, T. F., AND KRIEDEMAN, P. E. 467

1962. Reduction of plant transpiration by cetyl alcohol. Nature [London] 195(4847): 1221–1222.

Transpiration is reduced by cetyl alcohol, but this is related to reduction in growth and photosynthesis.

OERTLI, J. J. 468

1963. Effects of fatty alcohols and acids on transpiration of plants. Agron. J. 55(2): 137–138.

Fatty alcohols and acids applied to roots did not reduce water losses through transpiration without simultaneously reducing yields.—From auth. synop.

OLSEN, S. R., WATANABE, F. S., CLARK, F. E., AND KEMPER, W. D. 469

1964. Effect of hexadecanol on evaporation of water from soil. Soil Sci. 97(1): 13–18, illus.

Hexadecanol reduces evaporation of water from free-water surfaces, but the possibility that a similar action may occur with water in the soil has received little study. This paper reports on work done in Colorado, where water loss was decreased 43 percent in a 10-day period. Also, hexadecanol increased the infiltration rate.

PETERS, D. B., AND ROBERTS, W. J. 470

1963. Use of octa-hexadecanol as a transpiration suppressant. Agron. J. 55(1): 79.

The field studies reported in this paper did not indicate any appreciable reduction in transpiration after application of octa-hexadecanol.

POLJAKOFF-MAYBER, A., AND GALE, J. 471

1967. Effect of plant antitranspirants on certain physiological processes of forest seedlings and other plant material. Hebrew Univ. of Jerusalem. Project No. A10-FS-10, Grant No. FG-IS-145, Final Tech. Rep., 107 p.

A first step in this work was the laboratory screening of numerous film-forming plastic emulsions as antitranspirants and trials of these substances as to their effect on plant behavior. A number of materials were found which formed nontoxic films on the leaf and reduced transpiration by 20 to 40 percent.—From auth. sum.

ROBERTS, W. J. 472

1961. Reduction of transpiration. J. Geophys. Res. 66(10): 3309–3312.

The monomolecular-film technique for reducing evaporation from water surfaces has been applied to the problem of transpiration from plants. Hybrid corn grown in soil enriched by various amounts of fatty alcohols

such as hexadecanol has required up to 40 percent less water during its growth than control plants. It is theorized that some of the transpiration from corn plants can safely be reduced by the blocking action of molecules of hexadecanol carried through the plants and deposited at the stomate water-vapor interface. Although the blocking action could be taking place throughout the plants, testing with C^{14} hexadecanol has produced radio autographs showing activity not only in the roots and stalks but also throughout the leaves of treated corn plants. Comparative testing has been done in the greenhouse; however, one treated corn crop, grown naturally, yielded over 100 bushels per acre. Chemical tests on this corn showed no apparent effect of large doses of hexadecanol added to the roots of the plants.—Auth. abstr.

SILVESTON, P. L. 473

1965. Economics of water conservation with monomolecular films. Amer. Soc. Agr. Eng. Trans. 8(1): 127–134, 137.

This paper fully discusses past results and possible methods of application and gives examples of costs and probable savings in the use of monomolecular films on water surfaces.

SMITH, DON, AND BUCHHOLTZ, K. P. 474

1962. Transpiration rate reduction in plants with atrazine. Science 136(3512): 263–264.

When treated with atrazine, a herbicide that acts as an inhibitor of photosynthesis, both tolerant and susceptible plants showed a reduction in transpiration rate. This occurred within 1 to 3 hours of application and usually reduced transpiration by 50 percent or more after about 6 hours.—Auth. abstr.

See also 319, 681.

Stomatal Control of Water Losses and Chemical Effect on Stomatal Closure

GALE, J., AND POLJAKOFF-MAYBER, A. 475

1965. Anti-transpirants as a research tool for the study of the effects of water stress on plant behaviour. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 269–274, illus.

Because antitranspirants operate by directly reducing transpiration, they are proving to be a useful tool in the study of the effect of the transpiration stream on the uptake and transport of minerals and also in the experimental approach to the problem of the effect of transpiration on leaf temperatures. An experiment that demonstrated this is depicted in this paper; the transpiration of sugar beet plants was reduced by an antitranspirant spray.

In addition to their potentialities as reducers of irrigation water expenditure, anti-transpirants may prove to be a versatile research tool for water stress studies if their numerous side effects are taken into account.—From auth. sum.

IDSO, SHERWOOD B. 476

1968. Comments on paper by Richard Lee, "The hydrologic importance of transpiration control by stomata." Water Resour. Res. 4(3): 665–666.

This article states that, in his paper on the effects of stomata in regulating the rate of plant transpiration, Lee (1967, 477) fails to bring to fruition the main topic implied in the title of the paper. In his studies of diffusion rates through tubes of various sizes and single-pore and multipore nonliving membranes, he has shown that stomatal closing can greatly reduce the transpiration rates of plant canopies, but this demonstration in no way

indicates to what extent living plants do indeed so act in natural situations, and it is this second consideration that determines the importance to the hydrologic cycle of transpiration control by stomata and not the first. Thus, Lee has no basis in experimentation for drawing so absolute and general a conclusion as that "plant canopies are not passive evaporating surfaces." Such a deduction can come only from direct measurements of evapotranspiration from actual living crops, and many of these measurements carried out at the U. S. Agricultural Research Service, Water Conservation Laboratory near Phoenix, Ariz., indicate that this statement is only true for rather severe cases of water stress.—From auth. text.

Compiler's Note.—Lee made a strong reply to this criticism on pages 667–669, attempting to reinterpret some of the data published from the Water Conservation Laboratory and also stated: "Dr. Idso points to the hub of dissension that persists among process hydrologists: Are plants inert pumps that draw moisture from the soil and vaporize it in response to 'atmospheric demand'? Or do plants preferentially satisfy their own demands?"

LEE, RICHARD 477

1967. The hydrologic importance of transpiration control by stomata. Water Resour. Res. 3(3): 737–752, illus.

Plant canopies are not passive evaporating surfaces. The regulation of water loss from plants is an important function of leaf stomata, and significant stomatal regulation occurs throughout the range of leaf-pore diameters. Leaf pores do not 'interefere' with one another to any significant extent in the conductance of water vapor or other gases. The diffusive conductance of small pores is more sensitive to diameter changes at the larger apertures, thus permitting carbon dioxide exchange for photosynthesis without dehydration of the leaf mesophyll. In still air the external resistance over broad leaves limits control by stomata, but light drafts usually minimize this effect in field situations. Characteristic diffusion coefficients for leaf types, based on a careful study of leaf microstructure, physiology, and seasonal variations, are a rational basis for cover-type conversions or biochemical controls to reduce water loss. [This paper also presents an excellent review of literature on the process of transpiration control.]—Auth. abstr.

MONTEITH, J. L., SZEICZ, G., AND WAGGONER, P. E. 478

1965. The measurement and control of stomatal resistance in the field. J. Appl. Ecol. [Oxford] 2(2): 345–355.

The rate of evaporation from a crop is expressed in terms of weather parameters and a quantity r_s derived from profiles of temperature, humidity, and wind. In transfer equations, r_s is formally similar to the diffusion resistance of the stomata in a single leaf, and measurements in a field of barley support the hypothesis that r_s is the diffusion resistance of the complete crop canopy. The resistance is relatively small when the leaf area index is great, when soil is moist, and when sunlight is bright. It increases as the plants mature but is independent of wind speed and is, therefore, unrelated to the rate of diffusion by turbulent mixing.—From auth. sum.

PALLAS, J. E., JR. 479

1965. Transpiration and stomatal opening with changes in carbon dioxide contents of the air. Science 147 (3654): 171–173.

As the carbon dioxide content of the air increased from 2,000 to 4,000 p.p.m., stomata of several plant species were closed and transpiration was reduced.

SHIMSHI, DANIEL 480

1963. Effect of chemical closure of stomata on transpiration in varied soil and atmospheric environments. Plant Physiol. 38(6): 709–712.

Phenylmercuric acetate closed stomata and significantly reduced sunflower transpiration outdoors and tobacco transpiration in a greenhouse.

SHIMSHI, DANIEL 481

1963. Effect of soil moisture and phenylmercuric acetate upon stomatal aperture, transpiration, and photosynthesis. Plant Physiol. 38(6): 713–721, illus.

SMITH, DON, AND BUCHHOLTZ, K. P. 482

1964. Modification of plant transpiration rate with chemicals. Plant Physiol. 39(4): 572–578.

This article discusses studies on the effect of various chemicals on opening and closing of stomata.

VAN BAVEL, C. H. M. 483

1967. Changes in canopy resistance to water loss from alfalfa induced by soil water depletion. Agr. Meteorol. [Amsterdam] 4(3): 165–176, illus.

A field of alfalfa was irrigated and then allowed to deplete soil water reserves close to the −15 bar percentage during June 1964 in central Arizona. The average potential evaporation rate during the experiment was 9 mm./day.

From hourly measurements of the energy balance and ambient conditions over the field, the ratio between actual and potential evaporation was followed, and where significantly less than unity, interpreted as a canopy resistance to evaporation. This resistance did not become noticeable during the daytime until 20 days after irrigation and then rose rapidly to an average value of 15 sec./cm. on the last day of measurement, 31 days after irrigation. When significant, the canopy resistance typically showed a diurnal course with low values after sunrise, increasing up to 20-fold during early afternoon and then diminishing again.

The data imply that the alfalfa stomata exercised a regulatory role by holding the evaporation to a maximum value during the diurnal cycle. The maximum itself diminished from day to day as soil water was depleted.

The soil water potential in the root zone was estimated at −4 bars when stomatal control of evaporation first became noticeable. Further decrease of the soil water potential brought about sharply rising values of the daytime values of the canopy resistance. Qualitatively, this observation supports other evidence on the relation between soil water availability and water use by crop plants.—Auth. sum.

VAN BAVEL, C. H. M. 484

1968. Further to the hydrologic importance of transpiration control by stomata. Water Resour. Res. 4(6): 1387–1388.

An exchange of views (Idso 1968, 476) on the subject of the hydrologic importance of transpiration control by stomata revolves principally around results of several experiments carried out by the present author and former colleagues. Some clarifying comments appear in order since all relevant details were not published.

A general view must admit that, together with a number of internal and external conditions, leaf stomata determine the rate of transpiration. From a hydrologic or an engineering view, however, what matters is whether this role is of consequence. The issue can be settled only by a study of the transpiration from naturally exposed canopies of vegetation, of their atmospheric environment, and simultaneously, of the transpiration resistance of the leaves. Generalities derived from theoretical or simulation studies cannot supply the answer, and the present author agrees completely with similar comments made by Idso (1968, 476). Experiments in which vegetation is wetted by rain or artificially cannot be used as evidence, unless the complete energy balance is simultaneously studied. Experiments involving singly exposed

individual plants cannot inform us by simple analogy about the transpiration of natural stands.—From auth. text.

Compiler's Note.—Lee replied further to these remarks on pages 1389 and 1390.

VAN BAVEL, C. H. M., AND EHRLER, W. L. 485

1968. Water loss from a sorghum field and stomatal control. Agron. J. 60(1): 84–86, illus.

Measurements of temperature and diffusion resistance of leaves and of micrometeorological factors in a well-watered sorghum field during June in central Arizona show that the stomata regulate transpiration only during the periods of darkness and low light. This was concluded from a comparison of the values for the canopy resistance as derived from direct measurement on leaves and as calculated from the environmental data.

This finding predicts that, during the main part of the daylight period, neither an increase in number or aperture of stomata nor a wetting of the entire foliage would increase the evaporative flux. The action of the sorghum plant is then like that of a wick.—From auth. abstr.

VAN BAVEL, C. H. M., NAKAYAMA, F. S., AND EHRLER, W. L. 486

1965. Measuring transpiration resistance of leaves. Plant Physiol. 40(3): 535–540, illus.

A method, suitable for field use, is given whereby the resistance offered by the leaf anatomy to diffusive loss of water can be measured directly, rapidly, and with simple, portable equipment.

A small cup, containing a sensitive humidity sensor, is clamped onto the leaf and the time rate of change of the sensor indication is measured over a short period, often less than 1 minute. Appropriate calibration permits the conversion of the time rate of change to the diffusion resistance, inclusive of a temperature correction. Construction details of suitable, portable equipment are supplied.

The diffusion resistance, thus measured, can be used to compute the absolute transpiration rate of leaves and plants and to characterize the movements and responses of stomates with direct reference to the transpiration process.

The leaf resistance, as measured directly, can also be used in combination with a knowledge of atmospheric transport processes to predict evaporation from plant canopies.—Auth. sum.

WAGGONER, PAUL E. 487

1965. Transpiration of trees, and chemicals that close stomata. *In* International Symposium on Forest Hydrology. Nat. Sci. Found. Advan. Sci. Semin. Proc., Penn. State Univ., University Park, Pa., Aug. 29–Sept. 10, 1965. Pergamon Press, N. Y., p. 483–488, illus.

Since stomata can be closed by chemical spray and the transpiration of the leaf decreased, an interesting possibility for increasing streamflow has arisen. Success requires that stomatal resistance be a considerable proportion of the total resistance to transpiration from the forest, that transpiration consume a considerable proportion of the precipitation, and that the spray reach and close the transpiring stomata. The loss of water from jack pine (*Pinus banksiana* Lamb.) growing in 11 kg. of soil in cans was significantly decreased by sprays of phenylmercuric acetate. The leachate from lysimeters in which jack pine grew was increased significantly by sprays of phenylmercuric acetate. Since the glyceryl half-ester of decenylsuccinic acid sprayed on a watershed of the Coweeta Hydrologic Laboratory, in western North Carolina, did not strike the stomata-bearing undersides of the leaves, it was not determined whether stomatal closure will decrease transpiration and increase streamflow in a natural woodland.—From auth. abstr.

WAGGONER, P. E., MONTEITH, J. L., AND SZEICZ, G. 488

1964. Decreasing transpiration of field plants by chemical closure of stomata. Nature [London] 201(4914): 97–98.

Experiments demonstrated both the effectiveness of evaporation control by the chemical closure of stomata and the meteorological importance of stomatal resistance implicit in the analyses of Penman and Monteith.—From auth. sum.

WAGGONER, PAUL E., AND ZELITCH, ISRAEL 489

1965. Transpiration and the stomata of leaves. Science 150 (3702): 1413–1420, illus.

This paper includes many data on the relationships between environmental conditions, chemical sprays, and the size of stomatal openings. Also included is a discussion of the possibilities of conserving water by spraying chemicals upon vegetation. One study, which illustrates these savings used jack pines about 30 centimeters tall which were sprayed with phenylmercuric acetate. During five subsequent drying periods in the course of the ensuing 38 days, the sprayed plants lost 17 and 21 percent less water than the unsprayed ones, depending on the concentration of the chemical.

WOO, K. B., BOERSMA, L., AND STONE, L. N. 490

1966. Dynamic simulation model of the transpiration process. Water Resour. Res. 2(1): 85–97, illus.

As an approach to an integrated analysis of the dynamic system of water movement through the soil-plant-atmosphere continuum, a simulation model of the transpiration process is presented in this paper. Van den Honert suggested the use of Ohm's law describing water flow into, through, and out of plants. In the present study, this hypothesis has been expanded to include an analogous storage factor to deal with the dynamic flow of water in the plant. A set of differential equations and transfer functions is expressed in terms of water suction variables. The dynamic description of the water status in the plant is completed by introducing the system gain, which is a function of both the transpiration rate and the soil-water condition. The dynamic system gain is realized by a method similar to Corbin's method of a computer-controlled adaptive control system. The entire system is then simulated on an analog computer; its dynamic characteristics are investigated with consideration of various environmental effects.—From auth. abstr.

WOO, K. B., STONE, L. N., AND BOERSMA, L. 491

1966. A conceptual model of stomatal control mechanisms. Water Resour. Res. 2(1): 71–84, illus.

The stomata of plant leaves constitute a main regulating system of the transpiration process. Biologists have suggested a turgor mechanism to explain stomatal movement. The functions of the mechanism are quantitatively described by an osmotic water transfer theory or the active water transfer theory in the guard cells or both. Based on the active water transfer theory and the observations of stomatal movement under various conditions of water, carbon dioxide, and light, a conceptual model of the stomatal control mechanism is proposed. Transfer functions of the mechanisms characterizing the changes in turgor pressure have been derived. The entire system has been organized by the application of adaptive control system theory and has been simulated on an analog computer. The dynamic characteristics have been investigated with consideration of various environmental conditions.—From auth. abstr.

WOOLEY, JOSEPH T. 492

1966. Plant factors and transpiration—the individual leaf or plant. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 14–16.

This paper states that research is needed on the action of the stomata, on the control of this action, and on the consequences of such control.

ZELITCH, ISRAEL 493
1964. Reduction of transpiration of leaves through stomatal closure induced by alkenylsuccinic acids. Science 143(3607): 692–693.

ZELITCH, ISRAEL 494
1965. Environmental and biochemical control of stomatal movement in leaves. Cambridge Phil. Soc. Biol. Rev. [London] 40(4): 463–482.

This article describes some of the factors that control stomatal movement in turgid leaves and presents interpretations of some old and new observations. It is not yet possible to write the chemical reactions that would precisely account for the opening and closing of stomata, but one can begin to characterize these in a general way. A severe obstacle to a more detailed biochemistry of the guard-cell mechanism is the present inability to study guard-cell metabolism in a system completely isolated from the other cells of the leaf. The technique of using leaf disks of a convenient species and measuring stomata rapidly and accurately in large numbers of samples by means of impressions cast in silicone rubber has provided a reproducible means of investigating stomatal movement, and this method can be exploited further.—From auth. conclusions.

ZELITCH, ISRAEL, AND WAGGONER, PAUL E. 495
1962. Effect of chemical control of stomata on transpiration and photosynthesis. Nat. Acad. Sci. Proc. 48(7): 1101–1108.

Phenylmercuric acetate was effective in closing stomata of tobacco and corn.

ZELITCH, ISRAEL, AND WAGGONER, PAUL E. 496
1962. Effect of chemical control of stomata on transpiration of intact plants. Nat. Acad. Sci. Proc. 48(8): 1297–1299.

Spraying phenylmercuric acetate on the leaves of tobacco plants in the greenhouse consistently diminished transpiration, usually by more than half, while the effect on growth varied with environment.—From auth. sum.

PREDICTING MOISTURE LOSSES BY MEANS OF CLIMATIC PARAMETERS

GENERAL EMPIRICAL FORMULAE FOR DETERMINING EVAPOTRANSPIRATION, USING MAINLY TEMPERATURE, HUMIDITY, AND SUNSHINE HOURS

Comparison of Prediction Methods

AHMAD, M. S. 497
1961. Water requirements of plants in the Quetta Valley, West Pakistan. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 155–163.

After a detailed study of the methods of Penman and of Turc for evaluation of the water requirements of plants in arid and semi-arid areas, the conclusion has been reached that Penman's method allows satisfactory estimation of natural evaporation from an open water surface. This estimation can be used (pending the complete solution of Penman's equation for a fully

transpiring surface) for evaluating the potential transpiration (or water need) of plants in arid and semi-arid regions. It is suggested that rather higher values of the coefficient *f* which relates the natural evaporation from a free water surface and the potential transpiration) may be needed in arid and semi-arid areas. It may in fact be not far from unity. Until this question is completely resolved the empirical equations of Turc meet the need fairly adequately. In this paper Turc's expression for soil moisture (term *a*) has been adjusted to suit local conditions in the Quetta Valley, West Pakistan. The writer has used Turc's method (so modified) for working out the complete water balance of bare as well as cultivated soil (wheat crop) in the valley.—From auth. conclusion.

AMERICAN SOCIETY OF CIVIL ENGINEERS 498

1966. Methods for estimating evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2–4, 1966. Amer. Soc. Civil Eng., N. Y. 236 p., illus.

This conference covered estimation of evapostranspiration by empirical formulae, evaporation pans, and climatic data for use in water development projects. Abstracts of most of the articles are included in the present bibliography.

BAIER, W. 499

1965. The inter-relationship of meteorological factors, soil moisture, and plant growth (a review). Int. J. Biometeorol. [Canberra] 9(1): 5–20.

This thorough review of the literature gives consideration to prediction methods of estimating water losses.

BEHNKE, JEROLD J., AND MAXEY, GEORGE B. 500

1969. An empirical method for estimating monthly potential evapotranspiration in Nevada. J. Hydrol. [Amsterdam] 8(4): 418–430, illus.

Monthly potential evapotranspiration values were obtained for several stations throughout Nevada; the Thornthwaite and Olivier (1961, 510) equations were used. The Olivier equation correlated well with lysimeter and adjusted pan data as an estimate of evapotranspiration. On an annual basis the Thornthwaite equation was approximately 50 percent too low. A technique was developed to estimate wet bulb depression from temperature data. This made it possible to solve the Olivier equation by using only temperature data as input. Climatic conditions in Nevada were such that it was possible to apply the dry adiabatic lapse rate to a centrally located base station to obtain temperature values for other locations for which climatic data were lacking. On a monthly basis, this 'modified' Olivier equation correlated satisfactorily with the original equation for Nevada locations ranging in elevation from 2,171 to 5,136 feet and in latitude from 36° to 41° N.—From auth. abstr.

BRUTSAERT, WILFRIED 501

1965. Evaluation of some practical methods of estimating evapotranspiration in arid climates at low latitudes. Water Resour. Res. 1(2): 187–191.

A comparison is presented of monthly evapotranspiration data obtained by various methods for the valley of the Ruzizi River [Democratic Republic of the Congo]. Best agreement was noted between evaporation measured with a standard pan and that calculated with Penman's equation. The Blaney-Criddle and the Thornthwaite methods did not have adequate response to changes in evaporation potential, since temperature and day length varied little. Some improvement was observed with the Blaney-Morin method, which includes a humidity factor. [In general, pan evaporation data could be used rather reliably to predict gross evapotranspiration.]—Auth. abstr.

CHAPAS, L. C., AND REES, A. R. 502

1964. Evaporation and evapotranspiration in southern Nigeria. Roy. Meteorol. Soc. Quart. J. [London] 90(385): 313–319, illus.

Data are presented on a 4-weekly basis for 1961 and 1962 on evaporation from three types of evaporation pan and an evaporation estimate by Penman's method. Evapotranspiration was estimated by the methods of Penman, Blaney-Criddle, and Thornthwaite and by Garnier's (1954, 166) modification of Thornthwaite's method. Grass-covered lysimeters receiving only rainfall gave actual evapotranspiration, or were watered daily to give potential evapotranspiration. Actual evapotranspiration measurements are compared with theoretical estimates.

Potential evapotranspiration is overestimated by Thornthwaite's method and slightly underestimated by that of Penman. The true value is about 120 cm. annually, with a marked seasonal variation which follows the bimodal radiation cycle. Actual evapotranspiration is 50 cm. less than this, marked departure from the potential rate occurring during the main and subsidiary dry seasons.—From Auth. abstr.

COCHRANE, N. J. 503

1959. Observable evapotranspiration in the basin of the River Thames. Roy. Meteorol. Soc. Quart. J. [London] 85(363): 57–59.

The measurement of evapotranspiration from large land areas is, like the measurement of evaporation from large areas of water, a formidable problem and not often accurately accomplished. Nevertheless, where natural phenomena are concerned, it is essential for an engineer to try to check the results of theoretical or empirical analyses, or small-scale experiments, against nature. The results of an analysis of the hydrology of the basin of the Thames River are presented herein. Conclusions favoring the Thornthwaite method (over that of Penman) are reached.—From auth. sum.

CRIDDLE, WAYNE D. 504

1966. Empirical methods of predicting evapotranspiration using air temperature as the primary variable. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 54–56.

Practically all methods that have been developed for estimating water supply and irrigation-systems requirements use, at least in part, empirical coefficients to relate basic climatic factors with plant needs. Some of the methods suggested require a minimum of basic data, and others are only applicable in transferring water requirement data from one well-instrumented research station to another and are not readily adapted for use in areas of the world where the greatest need for such information exists. For many areas even temperature and precipitation data are far from adequate. Thus, anyone using methods requiring sophisticated data simply ends up with a number of estimated factors instead of a more general coefficient encompassing several unknowns.

We might also question the accuracy of any specific consumptive-use data measured under the widely varying experimental conditions encountered during a single year or even during several years. Certainly crops grown in lysimeters are not under exactly the same environment as those grown in the field, as a comparison of crop yields will usually indicate.

A brief description is given of the Lowry-Johnson (1941, 569) and Blaney-Criddle methods of computing agricultural water requirements.

Although more sophisticated methods of estimating water requirements are highly desirable, water resource planning is under way all over the world using inadequate temperature and precipitation data as a basis of determining cropping patterns and irrigation-water needs. Such determinations leave much to be desired for the planner and operator. New projects cannot wait

for new methods of estimating water needs to be developed. Thus, it is extremely important that we put together the information we now have and keep it usable.—From auth. introd. and sum.

CRUFF, R. W., AND THOMPSON, T. H. 505

1967. A comparison of methods of estimating potential evapotranspiration from climatological data in arid and subhumid environments. U. S. Geol. Surv. Water-Supply Pap. 1839-M, 28 p., illus.

This study compared potential evapotranspiration as computed from climatological data by each of six empirical methods: Those of Thornthwaite; the U. S. Weather Bureau—a modification of the Penman method by Kohler, Nordenson, and Fox (1955, 378); Lowry-Johnson (1941, 569); Blaney-Criddle; Lane (1964, 380); and Hamon (1966, 565). Necessary tables and nomographs for use of these methods are given.

The test was limited to 25 sites which sampled a wide range of climatic conditions in the arid and subhumid parts of Arizona, California, and Nevada, where pan evaporation and concurrent climatological data were available. However, some of the sites lacked complete climatological data for the application of all six methods.

Only the Weather Bureau method gave estimates of potential evapotranspiration that closely agreed with the adjusted pan evaporation at all sites where the method was used. Unfortunately, lack of the necessary climatological data restricted the use of the Weather Bureau method to seven sites. Results obtained by use of the Thornthwaite, Lowry-Johnson, and Hamon methods were consistently low. Results obtained by use of the Lane method agreed with adjusted pan evaporation in arid environments but were consistently high in irrigated or subhumid environments. The results of this study for the latter environments indicated that the Blaney-Criddle method, which uses climatological data that can be readily obtained or deduced, was the most practical of the six methods for estimating potential evapotranspiration. At all 15 sites in these two environments, potential evapotranspiration computed by the Blaney-Criddle method checked with the adjusted pan evaporation within ± 22 percent. This percentage range is generally considered to be the range of reliability for estimating lake evaporation from evaporation pans.—From auth. abstr.

DAMAGNEX, J., RIOU, CH., DE VILLELE, O., AND EL AMMAMI, S. 506

1963. Estimation et mesure de l'évapotranspiration potentielle en Tunisie. General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 98–113. [In French]

Compiler's Note.—According to Cruff and Thompson (1967, 505), this article compared the Thornthwaite, Blaney-Criddle, Turc (1955, 576), and Penman methods of estimating potential evapotranspiration from climatological data with measurement of evapotranspiration by nonweighing lysimeters. The study used data from five sites in Tunisia. The climate at the five sites ranged from Mediterranean to hot desert. For the Tunisia area the authors found that only the Penman and the Turc methods gave acceptable estimates of potential evapotranspiration.

JENSEN, MARVIN E. 507

1966. Empirical methods of estimating or predicting evapotranspiration using radiation. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc.,, Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 49–53, 64, illus.

Empirical methods are used for estimating or predicting evapotranspiration when (*a*) inadequate meteorological and soil-crop data are available for use

in applying complete rational equations based on the physical processes involved or (*b*) the accuracy of the data needed may be adequate if simple empirical equations that require much less time and effort to solve are used. Also, empirical methods are used because complete rational equations often require greater technical ability and experience in meteorology, physics, and agronomy than many users of evapotranspiration data have or can justify attaining.

MUNSON, WENDELL C. 508

1960. Method for estimating consumptive use of water for agriculture. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 86 (IR 4): 45–57.

Estimates of monthly and annual consumptive use of water for agriculture are essential for the planning of potential irrigation projects. Formulas have been developed which consider complex functions of the many variables involved and result in mathematically exact computations of evapotranspiration which may vary considerably among the different formulas, depending upon the researchers' evaluation of the various factors involved.

This paper presents data on measured rates of consumptive use of water, as well as estimated consumptive use determined by various formulas, and describes a procedure for determining monthly and annual water requirements, on a project basis, from climatological data for areas where measurements of consumptive use are not available. The simple method for estimating consumptive use of water for agriculture is called the precipitation-evaporation, or P.E., index method.—From auth. synop.

NIXON, PAUL R., MACGILLIVRAY, NORMAN A., AND LAWLESS, G. PAUL 509

1963. Evapotranspiration-climate comparisons in coastal fogbelt, coastal valley and interior valley locations in California. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 221–231.

Evapotranspiration from irrigated alfalfa was observed in coastal fogbelt, coastal valley, and interior valley locations in California, all near 35° N. latitude. Evapotranspiration was depressed within the influence of the ocean, in the fogbelt area, where there was a steep climatic gradient with distance from the ocean. Evapotranspiration rates in the three areas during the months of June through September are compared with solar radiation, temperature, vapor pressure deficit, wind, standard U. S. Weather Bureau pan evaporation, and atmometer evaporation. Pan evaporation and solar radiation correlated best with evapotranspiration. Two empirical methods of estimating evapotranspiration did not perform well in the areas studied.—Auth. sum.

OLIVIER, HENRY 510

1961. Irrigation and climate. Edward Arnold Pub. Ltd. [London] 250 p., illus.

Most of the commonly used methods of predicting evapotranspiration losses are discussed in full in this book, and a new approach is outlined.

PENMAN, H. L. 511

1963. Vegetation and hydrology. Commonwealth Bur. of Soils, Farnham Royal, Bucks, England, Commonwealth Agr. Bur. Tech. Commun. 53, 124 p.

This book reviews general problems of hydrology and includes a general discussion of the relationship of vegetation and rain and detailed discussions of interception, infiltration, runoff, and erosion. Chapter 4 (Evaporation, Transpiration, and Evapotranspiration) discusses general principles and outlines in detail the use of evaporation formulae by Blaney-Criddle, Thornthwaite, Penman, and Turc. The author considers that all these formulae are

of value primarily when water is a nonlimiting factor. He points out that the early students of transpiration converted their data into ratios of water transpired to dry matter produced and that these ratios are very difficult to apply.

A great deal of information is given on the actual water use of various crops. The author quotes many different workers and gives tables of the values which they found. He also discusses the relationship of soil moisture to evapotranspiration losses. The last section of the book covers experiments throughout the world on watershed or catchment areas. There are short, concise tables which cover watershed studies in Japan, Europe, Africa, and the United States.

PRUITT, W. O. 512

1960. Relation of consumptive use of water to climate. Amer. Soc. Agr. Eng. Trans. 3(1): 9–13, 17.

The relationship between consumptive use of water and evaporation from pans remained fairly constant throughout the season regardless of the type of pan. The larger ground pans and the U. S. Weather Bureau class *A* pan were somewhat more consistent in their relationship than the smaller aboveground pans. Atmometer results showed a close correlation of evaporation from these devices and consumptive use.

Results again demonstrated the desirability of using a variable *K* factor for the Blaney-Criddle procedure under conditions studied. The Thornthwaite procedure required the use of a coefficient of 1.72 in estimating consumptive use of water by clover. This would indicate that the accuracy of the Thornthwaite method may be quite variable, depending on the type of climate encountered. The effect of abnormal weather conditions on the accuracy of both methods was shown to be quite adverse.

The very high correlation in semi-arid central Washington of consumptive use and estimates made by a procedure developed in the vastly different climate of England indicates the wide adaptibility of Penman's procedure. However, the need for a somewhat higher crop coefficient for Washington conditions was shown.

The results of this study show a very close correlation of consumptive use and climate. The fact that the relationship between consumptive use and estimated use remained quite constant throughout the season for all the pans, the atmometers, and Penman's procedure, shows that estimates based on use of these devices and this method should be quite reliable for predicting consumptive use for crops which have an ample moisture supply and are fully shading the ground.—From auth. sum.

PRUITT, W. O., AND JENSEN, M. C. 513

1955. Determining when to irrigate. Agr. Eng. 36(6): 389–393.

Rates of consumptive use of water by four crops grown at the Irrigation Experiment Station at Prosser, Wash., are presented. Rates of evaporation from a U.S. Bureau of Plant Industry evaporation tank, along with the consumptive-use rates estimated by use of the Blaney-Criddle and Thornthwaite procedures, are compared with measured consumptive-use rates.

During periods of good crop cover, tank-evaporation rates gave a much closer estimate of actual consumptive-use rates than either the Blaney-Criddle or Thornthwaite procedure. Although high correlation coefficients resulted from statistically comparing each of the three methods with consumptive use, it was found that for the Blaney-Criddle method the value for the crop coefficient should vary throughout the season. Estimates of consumptive use with the Thornthwaite procedure fell short of actual consumptive use, but by applying a constant crop factor, depending on the crop, they were adjusted to provide closer correlation.

Comparisons of the past 32 years' data on evaporation during July with estimated consumptive use and with actual consumptive use for alfalfa during 4 of the last 6 years indicate some problem in adjusting the Thornthwaite

or the Blaney-Criddle procedure for this area, especially for scheduling irrigation. The quite favorable results obtained with the evaporation pan show promise that the principle of its use may be applicable in determining when to irrigate.—From auth. sum.

RIJTEMA, P. E. 514

1959. Calculation methods of potential evapotranspiration. Wageningen Inst. voor Cult. en Waterhuishouding Tech. Bull. [The Netherlands] 7: 1–10, illus.

Values of potential evapotranspiration, calculated with the formulae of Penman, Makkink [1957, 536], Turc [1955, 576], and Haude [1954, 568], have been compared with measured values from a pan and from lysimeters covered with grass.

In the calculations with Penman's formula, calculated values of the relative sunshine have been used. There is a good agreement for 10-day periods between E_O calculated after Penman and the evaporation of the pan.

Haude and Uhlig [1954, 578] give coefficients, with which Haude's formula must be multiplied to get values of the potential evapotranspiration. These coefficients do not give correct results at Wageningen [the Netherlands]. A new reduction factor was calculated, consisting of a day-length factor and a wind-velocity factor. It is possible to calculate the potential evapotranspiration with the formulae of Penman, Makkink, and Turc with the same degree of accuracy as is obtainable with lysimeters or evaporation pans. Haude's formula gives results that seem to be somewhat less accurate. —Auth. sum.

ROBINS, J. S., AND HAISE, H. R. 515

1961. Determination of consumptive use of water by irrigated crops in the Western United States. Soil Sci. Soc. Amer. Proc. 25(2): 150–154, illus.

Certain of the many procedures for indirect estimation of consumptive use of water are discussed in this paper, including the Blaney-Criddle, Thornthwaite, and Penman methods, as well as evaporimeters such as atmometers and evaporation pans. The applicability and limitations in use of these procedures and devices are analyzed, including type and quality of data available, microclimatic effects, and use of derived information. Problems involved in determining evapotranspiration or consumptive use by irrigated crops are discussed, and their implications in use of data obtained for specific situations are analyzed. Subjects considered include sampling precision; frequency and time of sampling; crop rooting depth and stage of growth; type of crop; moisture status effects; climatic effects, including advected heat; and percolation losses beyond the sampling zone.—From auth. abstr.

STEPHENS, JOHN C., AND STEWART, ERNEST H. 516

1963. A comparison of procedures for computing evaporation and evapotranspiration. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 123–133, illus.

Comparison of correlation coefficients for measured versus computed monthly pan evaporation in southern Florida over a 6-year period showed the U. S. Weather Bureau method [Kohler, Nordenson, and Fox 1955, 378] ranked highest and the Thornthwaite method lowest of nine methods. In a similar comparison for 30 months of measured versus computed potential evapotranspiration from St. Augustinegrass, a fractional evaporation equivalent method ranked highest and the Thornthwaite method again ranked lowest. Evapotranspiration was predicted with more accuracy than pan evaporation.—Auth. abstr.

STORK, C. 517

1959. Evapotranspiration problems in Iraq. Neth. J. Agr. Sci. [Wageningen] 7: 269–282.

The Dujailah Experimental Station, situated in the river plain of Mesopotamia, was established in 1955 by the Development Board of Iraq for the study of the reclamation and salinity control of saline and alkali soils of Mesopotamia.

As a result of this study, it can be stated that in general the Penman formula seems to be in agreement with the empirical results of the Dujailah experimental fields, whereas the usefulness of the Blaney-Criddle equation is limited without determination of a monthly *K* factor for the area concerned. Thornthwaite's formula, like the Blaney-Criddle method, is based on a correlation between radiation and temperature, but since this formula has no crop coefficient in which other factors influencing the evapotranspiration can be concluded, no practical results would be obtained by using it.—From auth. sum.

TOKSOZ, SADIK 518

1961. Evapotranspiration in the Seylan Plain in southern Turkey. *In* Int. Cong. Soil. Sci. Trans. [Amsterdam]. (7th) Madison, Wisc. 1960. v. 1: 210–216.

The results of four methods of calculating evapotranspiration or "consumptive use" are compared. It is pointed out that the Lowry-Johnson (1941, 569) and Blaney-Criddle methods cannot be used unless correlation factors and crop coefficients are established by local experiments. The methods of Penman and Thornthwaite lead to satisfactory results if appropriate meteorological data are available. The Penman method is discussed in some detail, and an illustrative computation is included for 1947.—From auth. sum.

TOMLINSON, BYRON R. 519

1953. Comparison of two methods of estimating consumptive use of water. Agr. Eng. 34(7): 459–460, 464, illus.

This report compares the Lowry-Johnson (1941, 569) method of estimating consumptive use of water with the Blaney-Criddle method. The Pinedale area of the Green River Basin of Wyoming was used as a test site. By utilizing surface measurements and soil moisture determinations during the growing season of 1951 and subtracting rainfall of 1.8 inches, it was determined that 8.4 inches depth of irrigation water were utilized. By comparison, the Lowry-Johnson computation method predicted an annual consumptive use of 18 inches. The Blaney-Criddle method indicated a water requirement of 8.9 inches.

VAN BAVEL, C. H. M., AND WILSON, T. V. 520

1952. Evapotranspiration estimates as criteria for determining time of irrigation. Agr. Eng. 33(7): 417–418, 420.

The Blaney-Criddle, Penman, and Thornthwaite formulas were used in calculating evapotranspiration losses at Raleigh, N. C. The first was closest to measured evaporation, the other two were somewhat higher than actual.

See also 18, 19, 22, 25, 29, 591, 677, 684–686.

Thornthwaite Formula

HANTUSH, MADHI S. 521

1959. Potential evapotranspiration in areas along the rivers of New Mexico. N. Mex. Inst. of Mining and Tech. Prof. Pap. 101, 27 p., illus.

Along the rivers of New Mexico, the ground water is being discharged continuously by the process of evapotranspiration. The closeness of the

water table to the land surface provides an abundant supply of water to the phreatophytic vegetation, so that the amount of water discharged by these plants or by evaporation from the soil is at the maximum rate of evapotranspiration, or what is known as the potential evapotranspiration. The Thornthwaite formula is basically an empirical relationship between potential evapotranspiration and mean air temperature, with adjustments for daytime hours, latitude, and soil-moisture content. Thus, this formula can be used for any location at which daily maximum and minimum temperatures are recorded.

Values of potential evapotranspiration were computed by the Thornthwaite formula for areas along the major rivers of New Mexico where records of temperature were available. Climatological records compiled by the State Engineer were used.

LEEPER, C. W. 522

1950. Thornthwaite's climate formula. Aust. Inst. Agr. Sci. J. [Sidney] 16(1): 2–6.

MATHER, JOHN R. 523

1950. Manual of evapotranspiration. Suppl. to Interim Rep. No. 10, Micrometeorology of the Surface Layer of the Atmosphere, April 1, 1950, to June 30, 1950. The Johns Hopkins Univ., Lab of Climatol., Seabrook, N. J. 29 p., illus.

This manual explains the concept of potential evapotranspiration, describes the instruments that have been developed to measure it, and supplies instructions for making and analyzing the observations. Besides bringing together much of the already published material, it includes many of the unpublished results and observations obtained from 3 years of work at Seabrook, N. J., and other places. These observations reveal some of the limitations of the instrumentation as well as some of the requirements for obtaining representative measurements of potential evapotranspiration.—From auth. foreword.

PALMER, WAYNE C., AND HAVENS, A. VAUGHN 524

1958. A graphical technique for determining evapotranspiration by the Thornthwaite method. Mon. Weather Rev. 86(4): 123–128, illus.

Generalized diagrams for the determination of evapotranspiration and potential evapotranspiration in accordance with the empirical equations of Thornthwaite are presented.

PELTON, W. L., KING, K. M., AND TANNER, C. B. 525

1960. An evaluation of the Thornthwaite and mean temperature methods for determining potential evapotranspiration. Agron. J. 52(7): 387–395, illus.

Measurements of potential evapotranspiration indicate that mean temperature cannot be relied upon for general use in estimating evapotranspiration during short periods. Mean temperature methods can be used with limited success for long period (growing season or annual) estimates of potential evapotranspiration, but energy-balance methods are preferable if radiation data are available.—Auth. synop.

THORNTHWAITE, C. W. 526

1948. An approach toward a rational classification of climate. Geogr. Rev. 38(1): 55–94, illus.

This report, which includes a general classification of climate, devotes a section to the problems relating to measurement and mapping evapotranspiration as a climatological factor.

The term "potential evapotranspiration" was defined as the amount of

water lost from a wet surface or one completely covered with vegetation if there is moisture available at all times.

In his method of determining potential evapotranspiration, the author holds temperature and day length to be most important. The former should integrate the radiation exchanges, air movement, humidity, and other meteorological factors affecting vapor movement. The latter adjusts for effect of latitude upon sunshine hours during the water loss season.

The steps for determining potential evapotranspiration at a particular site are outlined and tables and nomographs included to make the complicated computations practical.

Compiler's Note.—Cruff and Thompson (1967, 505) include the same material in their paper on a comparison of methods of estimating potential evapotranspiration.

THORNTHWAITE, C. W., AND HOLZMAN, BENJAMIN 527

1939. The determination of evaporation from land and water surfaces. Mon. Weather Rev. 67: 4–11, illus.

Problems of measurement of evapotranspiration and transpiration from land and water surfaces are discussed and a formula utilizing factors of wind, temperature, relative humidity, and vapor pressure is presented.

THORNTHWAITE, C. W., AND HOLZMAN, BENJAMIN 528

1941. Evaporation and transpiration. *In* Climate and Man. U. S. Dep. Agr. Yearb. of Agr. 1941: 545–550.

This paper presents a general discussion of evaporation and transpiration. In view of the weakness of existing computative formulae for determining evapotranspiration, a new technique for measurement of moisture losses is presented. This measurement method uses a hygrothermograph to measure moisture content of the air and an anemometer to measure turbulence. The paper emphasizes the need for a more precise method.

THORNTHWAITE, C. W., AND HOLZMAN, BENJAMIN 529

1942. Measurement of evaporation from land and water surfaces. U. S. Dep. Agr. Tech. Bull. 817, 143 p., illus.

This study is an attempt to satisfy a longfelt need for a method of determining water losses to the atmosphere from land surfaces possessing various types of vegetal cover as well as from free water surfaces. Since the water entering the atmosphere becomes a gas and is invisible, direct methods such as those in use for measuring precipitation or runoff in streams cannot be employed.

Recent studies of turbulence in the lower levels of the atmosphere have supplied essential information that makes possible the determination of the rate of transfer of moisture from a natural surface into the atmosphere. An equation is here developed that gives this rate of moisture transfer in terms of measurements of wind velocity and humidity at two levels directly above the surface.

The measurements of both wind velocity and humidity must be made with a high order of accuracy. Thus, careful study of various types of hygrometers and anemometers was made, and some new instruments were designed and tested. A salt hygrometer, a chemical-absorption hygrometer, and a dewpoint recorder are described.

An evaporation station was established over a meadow at an experimental farm in Arlington, Va., in late autumn 1938. The station was operated through 1939, and a nearly complete hourly record of evaporation and condensation from the field was obtained. Tables presented in the bulletin include hourly values of temperature and of specific humidity at two levels and hourly values of wind movement at four levels. They also include daily totals of condensation and evaporation; this record is the first of its kind. There are a few unavoidable gaps in the record.—Auth. sum.

THORNTHWAITE, C. W., AND MATHER, J. R. 530

1955. The water budget and its use in irrigation. *In* Water. U. S. Dep. Agr. Yearb. of Agr. 1955: 346–358.

This paper discusses the measurement of evapotranspiration, including the "vapor transfer" method, and describes the evapotranspirometer which the authors feel is widely needed. The annual march of potential evapotranspiration and rainfall throughout the year is graphed for several localities to show periods of water surplus and drought.

THORNTHWAITE, C. W., AND MATHER, J. R. 531

1957. Instructions and tables for computing potential evapotranspiration and the water balance. Drexel Inst. of Tech. Lab. of Climatol. Pub. in Climatol. 10(3): 185–311.

This paper gives detailed information to aid in the computation of potential evapotranspiration. It includes many soil moisture retention tables which give the soil moisture retained after different amounts of potential evapotranspiration have occurred. Tables are prepared for various water-holding capacities of the root zone from 1 to 16 inches. This publication is the most complete discussion of the Thornthwaite method of computing potential evaporation.

See also 29, 165-183, 204, 345, 497-520, 505, 574, 591, 682-691.

Penman Formula

ABDEL-AZIZ, M. H., TAYLOR, S. A., AND ASHCROFT, G. L. 532

1964. Influence of advective energy on transpiration. Agron. J. 56(2): 139–142, illus.

The Penman formula and several modifications thereof were tested under semi-arid conditions. Neither the Penman formula nor any of the modifications adequately accounted for advective energy. Their deficiencies were particularly noticeable when high winds brought in energy during the night while other sources were supplying little or no heat.—Auth. abstr.

DAVENPORT, D. C., AND HUDSON, J. P. 533

1967. Meteorological observations and Penman estimates along a 17-km transect in the Sudan Gezira. Local advection over crops and fallow. II. Agr. Meteorol. [Amsterdam] 4(6): 405–414.

Daily measurements of maximum and minimum temperatures, wind velocity, and vapor pressure were made at windward and leeward edges of selected cotton fields, interspersed amongst uncropped fields, in the Gezira region of Sudan. Mean temperature, vapor pressure deficit, and wind run were lower at the leeward than the windward edges of the cotton. At comparable windward sites, wind run per day and mean daily temperature decreased as the downwind distance from the most windward edge of the 17-km. transect increased. Values of the evaporation, calculated by the Penman formula from meteorological data at various sites, were reduced by the presence of upwind stretches of cotton. Negative Bowen ratios indicated that advective conditions existed.—Auth. sum.

FITZPATRICK, EUGENE A. 534

1968. An appraisal of advectional contributions to observed evaporation in Australia using an empirical approximation of Penman's potential evaporation. J. Hydrol. [Amsterdam] 6(1): 69–94.

From data obtained in field studies of growth and water-use characteristics of cotton at Kimberley Research Station, Kununurra, Western Australia, a method was developed for obtaining an approximation of Penman's potential evaporation. The predictor used for this approximation is an adjusted version of a weighted vapor pressure deficit based on mean maximum screen temperature and found previously to provide an efficient basis for estimating

evaporation from the standard (sunken) Australian evaporation tank.

Daily data were used, and a distinctive linear relationship between the weighted vapor pressure deficit and Penman evaporation was identified for periods with low advection. An adjustment factor, based upon either the wet bulb depression or relative humidity, was then derived empirically to make this relationship applicable over a range of dryness conditions.

When applied with mean data over 10-day intervals, the method was found to give close agreement with Penman evaporation at four Australian stations having differing climatic environments. At all of these stations the approximated value is more highly correlated with the Penman evaporation than are the estimates of tank evaporation obtained from empirical relationships having either the unadjusted weighted vapor pressure deficit or the simple saturation deficit as the independent variable. At two extratropical stations, the correlation between Penman evaporation and the approximated value exceeds that between Penman and observed tank evaporation, but at tropical stations the latter correlation is slightly higher.

A broad regional application of the method is carried out, using published mean monthly climatic data for a network of 143 Australian stations. An index of advective strength derived as the ratio of the estimated tank evaporation (from the unadjusted weighted vapor pressure deficit) to the approximated Penman evaporation is also calculated. These parameters are mapped and discussed for summer and winter situations.—Auth. abstr.

FITZPATRICK, E. A., AND STERN, W. R. 535

1966. Estimates of potential evaporation using alternative data in Penman's formula. Agr. Meteorol. [Amsterdam] 3(3/4): 225–239, illus.

The work described in this paper was done at Kimberly Research Station, Kununurra, Western Australia, where there is a wide seasonal range of radiation and vapor-pressure deficit. The energy and aerodynamic components of Penman's evaporation formula were calculated daily for one year, and the potential evaporation was determined from several sources of data and by alternate modes of computation. Reference values for the energy component were obtained from measured net radiation over a well-watered crop. Reference values for the aerodynamic component were calculated from wet-and-dry bulb temperatures and windspeed; a relationship defined by Penman was used.

Total radiation and relative duration of sunshine were found to be effective alternative sources of data for the energy component. In calculating the effective terrestrial radiation, it was found that equally satisfactory results could be obtained from a relationship based on proposals by Swinbank (1951, 628) as by Penman's method, which includes a vapor pressure term. Daily Piche and tank evaporimeter data were found to be satisfactory alternatives to the aerodynamic component.

The conclusions reached are: (1) The minimal instrumentation needed to determine potential evaporation is a net radiometer, a Piche evaporimeter, and maximum and minimum thermometers, provided a suitable relation between the Piche and aerodynamic component is available. If a solarimeter is used in place of a net radiometer or sunshine recorder, a reliable albedo coefficient is necessary. When a sunshine recorder is used, a satisfactory relation between n/N and Q_t/Q_e is also required. (2) The use of inappropriate constants in the Penman formula is probably a greater source of error in determining potential evaporation than the deficiencies inherent in a particular type of instrument, e.g., a sunshine recorder. The constants appropriate to the particular climatic environment must be used.—From auth. sum.

MAKKINK, G. F. 536

1957. Testing the Penman formula by means of lysimeters. Inst. Water Eng. J. [London] 11: 277–288, illus.

This paper reports a discrepancy between the Penman calculation and

lysimeter results. It states that the discrepancy—on the average only 13 percent—is of little importance for practical purposes, but that it was found to be correlated with grass length. Two explanations are possible, and consequently, two ways in which correction may be made (eventually the two ways may be used in combination). The first concerns the roughness of the field and may be incorporated into an adapted wind formula. The second concerns extra radiation falling on the grass, depending on its height and the gap between the grass on the lysimeter and that outside. An estimate of this error is possible. The amount of extra radiation, estimated here, may be a severe warning to all workers with lysimeters: One should avoid every discontinuity between vegetation on and around a lysimeter. When the method of weighing makes a gap unavoidable, one should face the consequences. Grass should be kept very short.

There exists a possibility of correcting evaporation figures for grass length directly, without entering into the question of how it affects evaporation. From experience in 1955, when grass of four different lengths was simultaneously grown throughout the season, it appears that a correction for grass length may be made, but the analysis is not yet finished.

The big discrepancy between the Penman calculation and the observations on an open water pan requires more attention. This is in the opposite sense to the lysimeter discrepancy.

A comparison is in progress between the application of the Penman formula and simpler methods of determining potential evapotranspiration.—From auth. conclusion.

PENMAN, H. L. 537

1948. Natural evaporation from open water, bare soil and grass. Roy. Soc. Proc. Ser. A. [London] 193: 120–145.

Two theoretical approaches to evaporation from saturated surfaces are outlined: The first is on an aerodynamic basis, in which evaporation is regarded as due to turbulent transport of vapor by a process of eddy diffusion; and the second is on an energy basis, in which evaporation is regarded as one of the ways of degrading incoming radiation. Neither approach is new, but a combination is suggested that eliminates the parameter measured with most difficulty—surface temperature—and provides for the first time an opportunity to make theoretical estimates of evaporation rates from standard meteorological data, estimates that can be retrospective.

Experimental work to test these approaches shows that the aerodynamic approach is not adequate and an empirical expression, previously obtained in America, is a better description of evaporation from open water. The energy balance approach is found to be quite successful. Evaporation rates from wet bare soil and from turf with an adequate supply of water are obtained as fractions of that from open water, the fraction for turf showing a seasonal change attributed to the annual cycle of length of daylight. The experimental results are applied to data published elsewhere: It is shown that a satisfactory account can be given of open water evaporation at four widely spaced sites in America and Europe, the results for bare soil receive a reasonable check in India, and application of the results for turf shows good agreement with estimates of evaporation from catchment areas in the British Isles.—From auth. abstr.

PENMAN, H. L. 538

1949. The dependence of transpiration on weather and soil conditions. J. Soil Sci. [Oxford] 1(1): 74–89, illus.

The evaporation from an open-water surface can be estimated from weather data; the ratio of the transpiration from plentifully watered turf to the evaporation from similarly exposed open water is known as a function of time of year. These results of earlier work are restated and used as a

basis for estimating transpiration rates when optimum water supply is not maintained. It is assumed that the roots occupy a depth of soil which will yield a definite amount of water at maximum rate. After this amount is transpired, the rate is limited by the ability of the lower soil to transmit water; on the basis of earlier experimental work, a composite drying curve is drawn up. With this curve and the relevant weather data, it is possible to estimate the seasonal changes in the moisture content of soil under turf.—From auth. sum.

PENMAN, H. L. 539

1956. Estimating evaporation. Amer. Geophys. Union Trans. 37(1): 43–50.

Evaporation is a physical process that must satisfy two basic requirements. There must be an energy supply to provide heat of vaporization, and there must be some transport mechanism for removing the vapor. By combining these concepts it is possible to derive an expression for evaporation rate that depends only on measurable weather elements. By making some simplifying approximations, the weather data needed reduce to (*a*) duration of bright sunshine, (*b*) air temperature, (*c*) air humidity, and (*d*) wind speed. The quantity obtained is E_O, the evaporation rate for a hypothetical open water surface exposed to the measured weather. Formally, and empirically, it is possible to convert E_O into E_T, the potential transpiration rate from a short, green crop cover completely shading the ground and never short of water. This computation has formed the basis of successful experiments in irrigation control and, with reasonable empirical modification to allow for conditions when water supply becomes a limiting factor, has been applied with some success in studies of water balance of catchment areas. Applied to two classical American watershed studies, it suggests that some of the Coweeta [Coweeta Hydrologic Laboratory, in western North Carolina] results may need reconsideration. [Discussions by H. F. Blaney and H. G. Wilm are included].—Auth. abstr.

PURVIS, JOHN C. 540

1961. Graphical solution of the Penman equation for potential evapotranspiration. Mon. Weather Rev. 89(6):192–196, illus.

A practicable solution of the Penman formula for potential evapotranspiration by use of graphs is presented. For ease in computation, three graphs are used. These graphs, designed for Columbia, S. C., can be adapted for any location by relabeling or correcting two of the families of curves.—Auth. abstr.

SCHULZ, E. F. 541

1962. A graphical procedure to estimate potential evapotranspiration by the Penman method. Colo. State Univ., Civil Eng. Dep. CER62EFS49, 5 p., illus.

A series of graphs has been prepared to facilitate the use of the Penman equation to compute potential evapotranspiration. The general form of the Penman equation is somewhat impractical because the basic data are not extensively published. On the basis of some empirical relationships, a modified Penman equation has been developed. The computing graphs are similar to the graphs published by Palmer and Havens (1958, 524) for the Thornthwaite method and by Purvis (1961, 540) for the Penman method. The graphs given differ from the graphs published by Purvis in that the findings of Budyko (1958, 634) in connection with albedo have been included and Purvis' graphs are for one location—Columbia, S. C.—whereas these graphs could be used anywhere in the Northern Hemisphere up to latitudes of 60°. All scales are shown in the units normally used in publishing the data in the United States.—From auth. sum.

TANNER, C. B., AND PELTON, W. L. 542

1960. Potential evapotranspiration estimates by the approximate energy balance method of Penman. J. Geophys. Res. 65(10): 3391–3413, illus.

The energy balance approximation of Penman, used to estimate potential evapotranspiration, was tested for daily estimates on 37 days during 1956 and 1957. Though the Penman estimates were highly correlated with those obtained from detailed energy balance measurements, the absolute values of the Penman estimates were much too small. In order to obtain suitable daily estimates of evapotranspiration with the Penman method, a wind function that accounts for surface roughness and direct measurements of radiation energy were found necessary. The stomatal and day-length factors proposed by Penman and Schofield [1951, 446] appeared to have little basis for general application.—Auth. abstr.

VAN BAVEL, C. H. M. 543

1966. Combination (Penman type) methods. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich., 48 p.

A combination method of the Penman type can be used to calculate evaporation. It becomes a prediction method, if the climatology of the required variables is known. If it is assumed that the surface in question evaporates freely, potential evaporation can be calculated.

The utility of a combination method is restricted only by the availability of the necessary data. In water resources management *research,* required data should always be measured. In current engineering *applications,* its usefulness should always be explored, but one may have to settle for a temporary expedient of limited accuracy.

WANG, J. Y., AND WANG, S. C. 544

1962. A simple graphical approach to Penman's method for evaporation estimates. J. Appl. Meteorol. 1(4): 582–588.

The graphical determination of evaporation without direct measurement is the major concern of this paper. Nomographs are presented for use in estimating monthly evaporation by use of Penman's equation.

See also 18, 29, 168, 192, 193, 204, 225, 272, 497-520, 505, 572, 579, 580, 591, 598, 625, 639, 681, 682, 684.

Blaney-Criddle Formula

BLANEY, HARRY F. 545

1952. Consumptive use of water. Definitions, methods, and research data. Amer. Soc. Civil Eng. Trans. 117: 949–973, illus.

This paper discusses the subject of consumptive use (evapotranspiration) with special reference to definitions, methods, and results of research. The procedure to definitions, methods, and results of research. The procedure for determining consumptive use of water in valley areas from data on climate, irrigation, and other factors is outlined. The results of experimental measurements of evapotranspiration by agricultural crops and natural vegetation are presented briefly. The paper provides the practicing engineer the information required to estimate consumptive use in water utilization investigations.—From auth. synop.

BLANEY, HARRY F. 546

1952. Determining evapotranspiration by phreatophytes from climatological data. Amer. Geophys. Union Trans. 33(1): 61–66, illus.

Although evapotranspiration (consumptive use of water) by phreatophytes

has been measured at various times and places during the past 40 years, very little data are available in most sections of the United States. This paper presents data on measured evapotranspiration by phreatophytes and describes a method of determining rates of water consumption in areas where no measurements except climatological data are available. Briefly, the procedure is to correlate existing evapotranspiration data with monthly temperature, monthly percentages of yearly daytime hours, and growing period. The coefficients so developed for different kinds of vegetation are used to transpose the evapotranspiration data for a given area to other areas for which only climatological data are available.—From auth. abstr.

BLANEY, HARRY F. 547

1954. Consumptive use of ground water by phreatophytes and hydrophytes. *In* General Assembly of Rome, 1954. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 37: 53–62, illus.

This paper presents and describes, with several tables and graphs, the results of studies and measurements of the use of ground water by phreatophytes and hydrophytes in arid and semi-arid areas of five Western States (Arizona, California, Colorado, New Mexico, and Texas) and again describes the method of determining rates of water consumption in areas where no measurements except climatological data are available. The method is expressed in the empirical formulae developed first by Blaney and Morin (1942, 558).

BLANEY, HARRY F. 548

1954. Evapotranspiration measurements in Western United States. *In* General Assembly of Rome, 1954. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 38: 150–160, illus.

This paper describes field methods for determining water use and presents results of measurements of evapotranspiration by irrigated crops and natural vegetation in the Western United States. It repeats the description of a method for determining evapotranspiration in areas where no measurements are available.

BLANEY, H. F. 549

1954. Consumptive use requirements for water. Agr. Eng. 35(12): 870–873, 880.

This paper presents a full discussion of the Blaney-Criddle method for determining evapotranspiration and its application.

BLANEY, HARRY F. 550

1958. Monthly consumptive use of water by irrigated crops and natural vegetation. *In* General Assembly of Toronto, Sept. 3-14, 1957. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 44: 431–439, illus.

BLANEY, HARRY F. 551

1959. Monthly consumptive use requirements for irrigated crops. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 85(IR 1): 1–12, illus.

This paper presents extensive data on measured monthly amounts of consumptive use of water and seasonal consumptive use coefficients for different irrigated crops growing in the Western United States.

BLANEY, HARRY F. 552

1961. Consumptive use and water waste by phreatophytes. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 87(IR 3): 37–46, illus.

Information given in this presentation was taken from earlier publications. The analysis extends the very limited information on use of water by tamarisk to predict savings of water caused by replacement of tamarisk by grass along portions of the Pecos River, N. Mex.

BLANEY, HARRY F. 553

1961. Water consumption and salvage of water losses in phreatophyte areas. *In* Pacific Southwest Inter-Agency Committee Minutes of the 61–4 Meeting, Las Vegas, Nev., Nov. 29, 1961. p. 32–36. Processed.

This paper is a brief review of earlier information. Noteworthy are quoted figures from tanks at Safford, Ariz., (Gatewood, Robinson, Colby, and others. 1950, 364) where annual water loss from saltcedar was reported as 86.4 inches; from cottonwood, 72.0 inches; from baccharis, 56.4 inches; and from mesquite, 39.6 inches during 1943-44. These figures were computed on a basis of 100 percent volume density and must, therefore, be reduced to actual vegetation cover density before application in the field.

BLANEY, HARRY F., AND CRIDDLE, WAYNE D. 554

1950. Determining water requirements in irrigated areas from climatological and irrigation data. U. S. Dep. Agr., Soil Conserv. Serv. SCS-TP-96, 48 p., illus.

From the results of experimental studies throughout the Western United States, an empirical formula has been developed showing the relationship between temperature, length of growing season, monthly percentage of annual daytime hours, and consumptive use of water. By using this relationship, consumptive use and irrigation water requirements of crops can be quickly estimated for any area where the necessary climatological and irrigation data are available.

Briefly, the procedure is to correlate existing consumptive use data with monthly temperature, monthly percentages of yearly daytime hours, precipitation, and growing or irrigation season. Coefficients have been developed from existing measured consumptive use and temperature data and monthly percentages of yearly daytime hours. Thus, if only monthly temperature records are available and latitude is known, the consumptive use can be computed from the formula $U = KF$; where

U = Consumptive use of crop (or evapotranspiration) in inches for any period.

F = Sum of the monthly consumptive use factors for the period (sum of the products of mean monthly temperature and monthly percentage of daytime hours of the year).

K = Empirical consumptive use coefficient (irrigation season or growing period).

t = Mean monthly temperature, in degrees Fahrenheit.

p = Monthly percentage of daytime hours of the year.

$f = \frac{t \times p}{100}$ = Monthly consumptive use factor.

k = Monthly consumptive use coefficient.

$u = kf$ = Monthly consumptive use in inches.

This report gives a very complete list of consumptive use factors (f) for many localities in the West as well as K values for most of the crops raised in the various listed areas.

BLANEY, HARRY F., AND CRIDDLE, WAYNE D. 555

1962. Determining consumptive use and irrigation water requirements. U. S. Dep. Agr. Tech. Bull. 1275, 59 p., illus.

This report gives the most complete details on the application of the Blaney-Criddle formula in computing water use by various crops and republishes the following: 1. Tables of measured consumptive use for several

crops growing in different localities; 2. seasonal consumptive use coefficients (K) for irrigated crops; 3. nomograph for solution of the monthly consumptive use formula, $u = kf$; 4. sample tables showing method of computing irrigation requirements of several crops in various localities from f and k factors; and 5. monthly percentage of daytime hours of the year from 0° to 65° north and south latitude.

A full bibliography is given which includes many items on irrigation requirements of various States and regions.

BLANEY, HARRY F., AND CRIDDLE, WAYNE D. 556

1966. Determining consumptive use for planning water developments. *In* Methods for estimating evapotranspiration. Irrig. and Drainage Specialty Conf., Las Vegas, Nev., Nov. 2-4, 1966. Amer. Soc. Civil Eng., N. Y. p. 1–34.

This paper again describes the Blaney-Criddle method for estimating consumptive use of water and irrigation requirements for areas where few data, except limited climatological data are available. It summarizes the history and development of the Blaney-Criddle formula ($U = KF$) and gives some examples of its use in agriculture, the planning of irrigation projects, and settling of legal questions, not only in the United States but also in foreign countries. A list of State bulletins on water requirements for crops in the 17 States of the West is given. Also, seasonal consumptive use coefficients (K) for the important irrigated crops in the Western United States are listed.

BLANEY, H. F., HAISE, H. R., AND JENSEN, M. E. 557

1959. Monthly consumptive use by irrigated crops in Western United States. U. S. Dep. Agr., Agr. Res. Serv., Provisional Suppl. to SCS-TP-96, 53 p. Processed.

The monthly percentage of daytime hours of the year for various latitudes is shown in table 1 of this publication. Measured consumptive use of water and monthly coefficients calculated as described for a variety of field crops in various areas in the West are presented in table 2. Data for horticultural and specialty crops are presented in table 3. Coefficients relating to evaporation from U. S. Weather Bureau class A evaporation pans to the monthly "f" factor are presented in table 4.

BLANEY, HARRY F., AND MORIN, KARL V. 558

1942. Evaporation and consumptive use of water empirical formulae. Amer. Geophys. Union Trans. 23(1): 76–83, illus.

As part of an investigation sponsored by the National Resources Planning Board (Blaney and others, 1942, 142) to determine consumptive use of water along the Pecos River, a study was made of the relation of evaporation to evapotranspiration and to humidity and temperature, with the view of developing empirical formulae for estimating consumptive use of water in river valley areas where temperature and humidity records are available.

Consideration of these factors led to development of a monthly empirical formula:

$$e = k(tp)\ (114\text{-}h) = kf(114\text{-}h)$$

in which e = monthly evaporation in inches, k = monthly coefficient (varies with the type of pan or water surface), t = mean monthly temperature in degrees Fahrenheit, p = monthly percentage of annual daytime hours, $f = tp$ = monthly evaporative force (heat factor), and h = average monthly percentage of relative humidity.

A special study was made of data obtained during 1940 at an evapotranspiration station at Carlsbad, N. Mex., on evaporation, temperature, humidity, and precipitation; and on consumptive use of water by saltgrass, sacaton, tules, and saltcedar (tamarisk) grown in tanks placed in surroundings of natural growth. From above equation, a general monthly use formula:

$$u = kc$$

was developed, where u = monthly use of water (evaporation or consumptive use) in inches, k = monthly coefficient, and $c = f(114\text{-}h)$ monthly use index.

The value of k was determined from measured use and varies with the type of water surface and vegetation. The use index (c) represents factors of temperature, daytime hours, and humidity. Other factors influencing use of water, such as wind movement and barometric pressure, may be reflected in establishing values of k covering a sufficient range of average conditions.

The consumptive use formula is best adapted to native ground-water vegetation but may be used in estimating consumptive use by irrigated crops having access to an ample water supply, such as alfalfa, when some experimental evapotranspiration data are available for the crop, together with records of evaporation, temperature, and humidity.

It should not be inferred from the paper that the formulae can be universally applied. Coefficients should be developed for different climatic conditions in other regions from long-period climatological and evaporation data. —From auth. sum.

BLANEY, HARRY F., AND MUCKEL, DEAN C. 559

1955. Evaporation and evapotranspiration investigations in the San Francisco Bay area. Amer. Geophys. Union Trans. 36(5): 813–820, illus.

During 1953 and 1954 studies were made to determine probable evaporation and evapotranspiration losses that would occur if barriers were constructed across the San Francisco Bay to exclude salt water. This would create freshwater pools to conserve water for irrigation, domestic, and industrial use. Available measurements of evaporation and consumptive use of water by vegetation were compiled and analyzed. New climatological stations were established in areas not covered by existing stations and measurements made on evaporation, temperature, humidity, wind movement, and precipitation. Evaporation and consumptive use data were correlated with climatological records, and estimates were made of annual and monthly rates of evaporation from lake surfaces and consumptive use by marsh vegetation for the 1921-52 period and for the five critical years, 1923, 1924, 1930, 1931, and 1951.—Auth. abstr.

CRIDDLE, WAYNE D. 560

1953. Consumptive use and irrigation requirements. J. Soil Water Conserv. 8(5): 207–212, 243.

This paper discusses the factors affecting consumptive use of water (evapotranspiration), research studies of the problem, and methods of measuring and estimating consumptive use of agricultural crops. Nomographs have been developed for use in quickly determining monthly consumptive use rates, peak daily-use rates, and required flow rates for application in designing irrigation systems.

CRIDDLE, WAYNE D. 561

1958. Methods of computing consumptive use of water. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. (Paper 1507) 84 (IR 1):1–27, illus.

The author has summarized the more generally used methods for computing consumptive water requirements of crops. He has also included data and charts that may somewhat simplify the application of the methods.—From auth. abstr.

RANTZ, S. E. 562

1969. A suggested method for estimating evapotranspiration by native phreatophytes. *In* Geological Survey Research, 1968, U. S. Geol. Surv. Prof. Pap. 600-D: 10–12.

A graph and table have been developed for selecting values of the coefficient K to be used in the Blaney-Criddle formula for estimating evapotranspiration by native phreatophytes. Values of K are dependent on the species

of phreatophyte, the density of growth, and the depth to water table.—Auth. abstr.

See also 142, 204, 362, 497-520, 505, 591, 682, 684.

Other Methods

BENTON, GEORGE S., AND DOMINITZ, JACK 563

1956. Measuring evapotranspiration from atmospheric data. Amer. Soc. Civil Eng. Proc., J. Hydraul. Div. 82(HY4): 1–26, illus.

A method of evaluating evapotranspiration is presented which is based on the mass balance of water vapor in the atmosphere. The method is applied to various regions of the North American continent for the calendar year 1949, and the results are compared with hydrologic data and with an empirical method of estimating evapotranspiration.

It is shown that, although accurate values of evapotranspiration can be obtained for large areas, such as the entire continent, the accuracy of the method is reduced as the size of the area under consideration is decreased. The potentialities and limitations of the proposed method are evaluated.—Auth. synop.

HAMON, W. RUSSELL 564

1961. Estimating potential evapotranspiration. Amer. Soc. Civil Eng. Proc., J. Hydraul. Div. 87(HY3): 107–120, illus.

The equation developed to estimate average potential evapotranspiration has the desirable feature of requiring only readily available data. This equation seems generally applicable in view of the close correspondence between observed and computed values of average potential evapotranspiration, on both a yearly and seasonal basis for widely scattered localities.

HAMON, W. RUSSELL 565

1966. Evapotranspiration and water yield predictions. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 8–9, 13.

This paper states that a water-yield prediction model must incorporate adequate estimating functions for precipitation, retention, infiltration, evaporation or evapotranspiration or both, percolation, ground-water flow, and seepage losses. The equations developed to estimate the flow components for a small agricultural watershed clearly define the role of evapotranspiration in water-yield predictions.

HAUDE, WALDEMAR 566

1952. Verdünstungsmenge und Evaporationskraft eines Klimas. Germany Deutschen Wetterd. U. S. Zone Ber. [Bad Kissingen] 42: 225–229. [In German]

HAUDE, WALDEMAR 567

1954. Zur praktischen Bestimmung der aktuellen und potentiellen Evaporation and Evapotranspiration. Germany Deutschen Wetterd. Mitt. [Bad Kissingen] 8: 22 p. [In German]

HAUDE, WALDEMAR 568

1955. Zur Bestimmung der Verdüstung auf möglichst einfache Weise. Germany Deutschen Wetterd. Mitt. [Bad Kissingen] 11: 24 p. [In German]

Compiler's Note.—The formula for calculating potential evapotranspiration proposed and discussed by Haude (items 566–568) has been compared by Rijtema (1959, 514) to similar formulas.

LOWRY, ROBERT L., AND JOHNSON, ARTHUR F. 569

1941. Consumptive use of water for agriculture. Amer. Soc. Civil Eng. Proc. 67(4): 595–616.

Transpiration and evaporation, together accounting for practically all consumptive use of water, have been shown by experimental investigations to be influenced by climatic factors, of which temperature gives one of the better correlations. Consumptive use in a number of adequately watered irrigated valleys and humid watersheds, representing a wide range in climate, latitude, elevation, and type of crops, is shown in this paper to bear a straight-line relation, within narrow limits, to accumulated daily maximum temperatures above 32° F. during the growing season. Factors responsible for deviations from average consumptive use are discussed. The relation of consumptive use to growing-season temperatures offers to the engineer a ready means of estimating probable consumptive use on projects under investigation as an initial step in determining the irrigation requirements at the farm or at the point of diversion. Short descriptions of each area studied, with summaries of annual data, are given in the appendix.—Auth. synop.

Compiler's Note.—This article is reprinted with the discussions in Amer. Soc. Civil Eng. Trans. 107: 1243–1302. 1942. The graphic form of their equation is included in Cruff and Thompson (1967, 505).

MUNSON, WENDELL C. 570

1966. Estimating consumptive use by the Munson P.E. Index method. *In* Methods for Estimating Evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2–4, 1966. Amer. Soc. Civil Eng., N. Y. p. 65–107.

The method of estimating consumptive use of water described in this paper shows that monthly and annual consumptive use estimates may be determined for project formulation by utilizing only the average monthly temperatures and a set of predetermined precipitation-evaporation (P.E.) ratios. The results obtained by the P.E. index method have been compared with those obtained by many other methods over a wide geographical range and a great diversity of cropping procedures and crops. An earlier paper by the same author (1960, 508) has had worldwide distribution, and indications are that, with adjustments to meet different conditions, the results obtained by this method have been satisfactory. It is believed that the validity of the P.E. index method has been shown to be comparable to that of any other method and has the advantage of extreme simplicity.

Although the P.E. index method was not intended for use with individual crops or for very short periods of time, the results of several checks indicate that it may have possibilities for these purposes.

It should be stressed that any empirical formula will produce better results in the hands of its originator than it will in strange hands. Because of the great many influencing factors, most of which are generally not known, adjustment factors are necessary in all empirical formulas. Experience, common sense, and intimate knowledge of the formula derivation are as important as the formula itself. The use to which the results are to be put will generally determine the type of formula to be selected in any particular instance.—From auth. sum.

PIERCE, L. T. 571

1960. A practical method of determining evapotranspiration from temperature and rainfall. Amer. Soc. Agr. Eng. Trans. 3(1): 77–81.

A formula for use in determining evapotranspiration was developed from data obtained from lysimeters near Coshocton, Ohio. Evapotranspiration should equal potential evaporation as long as moisture is available and corrections are made for length of day, crop stage, rainy or cloudy days, and dryness of the soil.

PIKE, J. G. 572

1964. The estimation of annual run-off from meteorological data in a tropical climate. J. Hydrol. [Amsterdam] 2(2): 116–123.

A modified form of Turc's evapotranspiration formula is proposed and

used to predict annual runoff from large catchments in Malawi. The validity of Penman's conversion factor *f* as a seasonal factor for large catchments in a tropical climate with a seasonably unbalanced water regime is confirmed.—From auth. abstr.

ROBB, DAVID C. N. 573

1966. Consumptive use estimates from solar radiation and temperature. *In* Methods for Estimating Evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2–4, 1966. Amer. Soc. Civil Eng., N.Y. p. 169–191.

In connection with its current study of the use of water on federal irrigation projects, the U.S. Bureau of Reclamation required a method to estimate actual crop consumptive use (evapotranspiration) for time periods as short as 1 week, for a variety of crops on study areas located in most of the 17 Western States. The Jensen-Haise [1963, 651] method of estimating consumptive use from solar radiation and temperature was chosen as the basic approach. However, in order to simplify its application, the procedure was modified to allow the use of the Jensen-Haise potential evapotranspiration, rather than solar radiation alone as the "climatic factor." Revised crop curves for alfalfa, winter wheat, oats, sorghum, corn, potatoes, sugar beets, cotton, and beans have been derived; data supplied by Messrs. Jensen and Haise were used. Work is progressing on defining additional curves. Adjustments of the Jensen-Haise temperature correction factor for relative humidity are under consideration to allow its use in more humid areas. There is a need for additional information on the factors which, in addition to crop consumptive use, make up the total water requirement.—Auth. synop.

RUSSELL, R. L., AND BOGGESS, W. R. 574

1964. Evaluation of the Hamon method of determining potential evapotranspiration. Ill. Agr. Exp. Sta. Forest. Note 108, 4 p.

Based on data calculated for potential evapotranspiration and the water balance for the Lake Glendale Watershed, Pope County, Ill., from October 1, 1954, to September 30, 1962, a comparison is given in this publication of the Hamon method (1963, 564) of determining potential evapotranspiration and that of Thornthwaite. A graph is included showing a comparison of the average monthly data calculated by each method over the 8-year period. Average potential evapotranspiration over the 8-year period was calculated by the Hamon method to be 31.20 inches and by the Thornthwaite method to be 31.62 inches.

TURC, L. 575

1954. Le bilan d'eau des sols. Relations entre les précipitations, l'évaporation et l'écoulement. Ann. Agron. [Paris] 5(4): 491–595. [In French]

TURC, L. 576

1955. Le bilan d'eau des sols: Relations entre les précipitations, l'évaporation et l'écoulement. Ann. Agron. [Paris] 6(1): 5–131. [In French]

Compiler's Note.—Penman (1963, 511) states that the two formulae designed by Turc may be of value in determining evaporation where soil moisture may be limiting. He also states that the first formula is designed to relate annual evaporation from a watershed to rainfall and air temperature but that the second formula is more complex as it is intended to apply to short periods, taking into account soil-moisture variations and crop factors.

TURC, L. 577

1961. Evaluation des Besoins en eau d'irrigation, évapotranspiration potentielle. Ann. Agron. [Paris] 12(1): 13–49. [In French]

UHLIG, SIEGFRIED 578

1954. Berechnung der Verdunstung aus klimatologischen Daten. Germany Deutschen Wetterd. Mitt. [Bad Kissingen] 6: 24 p. [In German]

Compiler's Note.—Uhlig's study comparing the Penman and Haude (1954, 567) formulas is discussed by Rijtema (1959, 514).

VAN BAVEL, C. H. M. 579

1966. Potential evaporation: the combination concept and its experimental verification. Water Resour. Res. 2(3): 455–467, illus.

This paper reports on the formulation of an equation relating potential evaporation to net radiation, ambient air properties, and surface roughness. A combination of a surface energy balance equation and an approximate expression of water vapor and sensible heat transfer was used. As an improvement over the earlier Penman version, the proposed model contains no empirical constants or functions. Tests of the model in Phoenix, Ariz., using open water, wet bare soil, and well watered alfalfa, showed excellent agreement of calculated and measured values on an hourly and daily basis under a variety of circumstances. Test conditions typically included advection of sensible heat to the evaporation surface in a large portion to the latent heat flux, as well as high values of radiant flux, ambient temperatures, and vapor pressure deficits. The use of daily average values for the weather variables in the model, rather than hourly data, did not give appreciably different results or conclusions on a series of mostly clear days; this suggests that the combination model is not only accurate but also practical and generally applicable.—From auth. abstr.

VAN BAVEL, C. H. M., NEWMAN, J. E., AND HILGEMAN, R. H. 580

1967. Climate and estimated water use by an orange orchard. Agr. Meteorol. [Amsterdam] 4: 27–37.

Potential evapotranspiration from orange trees under the arid conditions of Arizona was estimated by the application of a modified Penman equation [van Bavel 1966, 579] to commonly logged climatic data. Since actual water use appears not to proceed at the potential rate but, rather, at a much lower one, stomatal transpiration resistance values were calculated. These values agree reasonably with directly measured values of stomatal resistance of sweet orange leaves, even though the weather and water use data used in this study were not specifically logged for the purpose at hand. The results demonstrate the potential power of a physical approach to the problem of predicting crop water use from standard climatic data.—Auth. abstr.

See also 29, 378, 497-520, 505, 572, 586, 682.

USE OF EVAPORATION DATA TO ESTIMATE EVAPOTRANSPIRATION LOSSES

Evaporation Pans

BLANEY, HARRY F. 581

1957. Relationship of pan evaporation to evapotranspiration by phreatophytes and hydrophytes. *In* Symposium on Phreatophytes, Pac. Southwest Reg. Meet., Amer. Geophys. Union, Sacramento, Calif., Feb. 14-15, 1957. Phreatophyte Subcom., Pac. Southwest Inter-Agency Comm. p. 26–31. Processed.

Evaporation measurements from pans have been used for many years in connection with water-supply studies to estimate evapotranspiration by phreatophytes. Usually, measurements of evaporation from U.S. Weather Bureau pans have been employed for this purpose. However, in some

instances, evaporation from other types of pans and atmometers has been used. This paper presents a comparison of pan evaporation and evapotranspiration by saltgrass, saltcedar, cottonwoods, and other natural vegetation in the Pacific Southwest. Ratios of water use (evapotranspiration) to evaporation are computed for the purpose of estimating evapotranspiration from evaporation pan records for areas where no water use measurements are available.—From auth. abstr.

CHRISTIANSEN, JERALD E. 582

1966. Estimating pan evaporation and evapotranspiration from climatic data. *In* Methods for Estimating Evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2-4, 1966. Amer. Soc. Civil Eng., N. Y. p. 192–234, illus.

Pan evaporation data are useful in estimating evaporation losses from reservoirs and lakes and for estimating evapotranspiration from agricultural crops by use of procedures, such as those of Hargreaves (1966, 586), Pruitt (1966, 589), or others, relating evapotranspiration to pan evaporation. Comparisons that have been made at Utah State University indicate that formulas utilizing climatic data can provide a satisfactory procedure for estimating pan evaporation. A revised pan evaporation formula was developed which, where climatic data are available, can estimate pan evaporation with a fair degree of accuracy for practically all climatic conditions.

The use of the tables for the coefficients and their logarithms makes this pan evaporation formula easy to apply. The formula is also useful even when all of the climatic factors included are not available.—From auth. sum.

CHRISTIANSEN, JERALD E. 583

1968. Pan evaporation and evapotranspiration from climatic data. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 94(IR 2): 243–265.

A dimensionally sound formula developed at Utah State University utilizes climatic data of the type most readily available, for estimation of pan evaporation. This article repeats in most respects the paper by Christiansen (1966, 582) and gives the same valuable information on many formulas for estimating moisture losses.

DALE, ROBERT F. 584

1966. Evapotranspiration and weather forecasts for agriculture. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 10–11, 13.

Evaporation pan measurements can be used in estimating daily soil-moisture use, based on studies of corn growing in three types of soil at Ames, Iowa.

DAVIS, JOHN R. 585

1963. Relationship of can evaporation to pan evaporation and evapotranspiration. J. Geophys. Res. 68(20): 5711–5718.

This paper presents a statistical comparison of evaporation from quart cans and a U.S. Weather Bureau class *A* pan for a humid and a semi-arid area. Correlations of can evaporation with pan evaporation were significant, and correlation of can evaporation with evapotranspiration was as good as that of pan evaporation. The results indicate that small cans merit consideration as a means of estimating evaporation or scheduling irrigation.—From auth. abstr.

HARGREAVES, GEORGE H. 586

1966. Consumptive use computations from evaporation pan data. *In*

Methods for Estimating Evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2-4, 1966. Amer. Soc. Civil Eng., N. Y. p. 35–64.

The needs for improved methods of calculating irrigation requirements are described. The history of the development of evaporation and evapotranspiration (consumptive use) formulas is briefly given, and improved evaporation formulas are presented. A basis for formula and method improvement consists of computer analysis of data. Ratios of evapotranspiration to class *A* pan evaporation (*Et/Ep*) are studied for a large number of crops. Crops are grouped into eight crop groups having similar consumptive use and irrigation requirements. Consumptive use coefficients for each of these groups are presented by 5 percent increments of the crop growing season or vegetative cycle. A formula is presented for converting consumptive use to irrigation requirements by allowing for suitable irrigation efficiency and for utilizable rainfall.—Auth synop.

HARGRAVES, GEORGE H. 587

1968. Consumptive use derived from evaporation pan data. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 94(IR 1): 97–105.

Evapotranspiration measurements or computations provide basic information for the computation of irrigation requirements. Unfortunately, in underdeveloped or developing countries both evapotranspiration and weather data are usually of limited availability and for some proposed project areas nonexistent. Formulas and methods are required by engineers working on design and development of irrigation. These must permit the evaluation of needs and requirements for irrigation with an absolute minimum of data. Formulas are given for computing evaporation from climatic data. Ratios of evapotranspiration to class *A* pan evaporation are given for a large number of crops. Crops are grouped together or assigned general classifications whenever possible. Consumptive use coefficients converting evaporation to evapotranspiration are given by 10 percent increments of the crop growing season or vegetative cycle. A method of computing utilizable rainfall is presented, and a formula is given for converting evapotranspiration to irrigation requirements. Irrigation requirements may be computed with several levels of data availability, provided temperature and rainfall measurements are at the disposal of the engineer; these measurements constitute a minimum of data required for the computation.—From auth. abstr.

MUKAMMAL, E. I. 588

1961. Evaporation pans and atmometers. *In* Symposium on Evaporation, Toronto, Canada, 1961. Canada Dep. N. Aff. and Nat. Resour., Water Resour. Br., Hydrol. Symp. Proc- [Ottawa] 2: 84–105.

A description is given of the most commonly used evaporation pans and atmometers. Comparisons are made between evaporation observed through use of some of these instruments and evaporation computed by mass transfer and energy budget methods. The characteristics, relative merits, representativeness, and usefulness of observations from these instruments are discussed.—From auth. synop.

PRUITT, W. O. 589

1966. Empirical methods using primarily evaporation pans. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 57–61, illus.

Where reliable measurements have been made and where pan environment has been fairly well standardized throughout the growing season,

results indicate, by and large, that pan-evaporation data could be very useful as a practical tool for estimating potential evapotranspiration. Two problems, local pan environment and strong advection, which can very significantly affect evapotranspiration-evaporation relationships are discussed. The importance of standardized local pan environment is shown. The serious effect of strong advection on the relationship between evapotranspiration and evaporation, especially in conjunction with strong dry winds is illustrated.—From auth. sum.

SHAW, R. H. 590

1964. Prediction of soil moisture under meadow. Agron. J. 56(3): 320–324, illus.

The potential rate of evapotranspiration from cropland was estimated from class *A* open-pan evaporation data. This was correlated successfully to soil moisture.

STANHILL, G. 591

1961. A comparison of methods of calculating potential evapotranspiration from climatic data. Israel J. Agr. Res. [Rehovot] 11(3/4): 159–171, illus.

The research results reported in this paper indicate that, of eight methods tested of calculating potential evapotranspiration (including the Thornthwaite, Blaney-Criddle, and Piche evaporimeter methods), those based on open water evaporation, measured in standard evaporation tanks or pans or estimated by Penman's method, are the best.

STANHILL, G. 592

1962. The control of field irrigation practice from measurements of evaporation. Israel J. Agr. Res. [Rehovot] 12(2): 51–62, illus.

The relations of evapotranspiration to evaporation pan data are presented for several crops in Israel.

WEAVER, H. A., AND STEPHENS, J. C. 593

1963. Relation of evaporation to potential evapotranspiration. Amer. Soc. Agr. Eng. Trans. 6(1): 55–56.

The standard class *A* evaporation pan appears to have a real value as an index of crop-water requirements in the area of southern Florida where management does not permit soil water to become limiting.

See also 344, 677, 679, 682.

Atmometers and Similar Devices

BOUCHET, R. 594

1961. Évaporation sous abri et évapotranspiration potentielle. *In* Plant-Water Relationships in Arid and Semi-Arid Conditions. Madrid Symp. [Madrid, 1959] Proc. UNESCO Arid Zone Res. [Paris] 16: 27–32. [In French with English summary.]

Shaded evaporimeters (e.g., the Piche apparatus) are in common use at meteorological gauging stations. Unfortunately the correlation between these readings and potential evapotranspiration is at best very poor; for example, the Piche readings in the Paris area and in the equatorial forests of the Congo are more or less the same.

These apparently aberrant results can be explained by abstract analysis of the phenomenon in terms of "boundary layer" mechanics. Such analysis shows that, to arrive at the potential evapotranspiration from the shade evaporation readings, a correction factor must be introduced, based solely on temperature.

Thus, the daily temperatures and Piche evaporation readings together give a corrected daily evaporation figure which will more nearly represent potential evapotranspiration and permit all necessary comparisons to be made with respect to time and space.—From auth. sum.

HALKIAS, N. A., VEIHMEYER, F. J., AND HENDRICKSON, A. H. 595

1955. Determining water needs for crops from climatic data. Hilgardia 24(9): 207–233, illus.

The best measure of water use by crops is found by soil sampling to obtain the changes in soil moisture. Reproducible results are obtained by this method if there is a long, rainless period during the growing season and if irrigations are far enough apart so that at least three samplings may be obtained between waterings.

The difference in evaporation between black and white atmometers has shown a high correlation with the use of water by crops and also with the solar radiation as measured by an Eppley pyrheliometer.

Loss of water from a given area is associated with the energy received from the sun and the ground coverage of the plants as long as the soil moisture is above the permanent wilting percentage.

Rates of use of water by crops may vary from year to year, but if the ground coverage is equal, the use is the same in any given year, in spite of the size of the individual plants. Large differences in loss of water by crops may occur if the coverage of the ground by the plants differs.

The correlation between evaporation from a white atmometer and from a standard U.S. Weather Bureau pan suggests that the former could be substituted for the latter for measurement of evaporation.—Auth. abstr.

MUELDER, DIETRICH W., TAPPEINER, JOHN C., AND HANSEN, JACK H. 596

1963. Measurement of potential evaporation rates in ecology and silviculture with particular reference to the Piche atmometer. J. Forest. 61: 840–845.

Knowledge of the drying power of the air at the plant site provides insight into important environmental conditions. Measurements of potential evaporation rates are, therefore, indispensable in ecological and silvicultural research. The Piche atmometer lends itself to measurements within the vegetation canopy as well as in the air layer close to the ground. The instrument is both inexpensive and easy to operate, thus allowing simultaneous measurements at several localities. Compared to the magnitude of significant environmental differences, the errors due to the shortcomings of the simple instrument are negligible. The use of the instrument is explained in this paper, and examples are given from studies on early seedling survival in the mixed conifer type of the westside Sierra Nevada in California. Measurements at 1 inch above the ground, with a reference reading at 40 inches, helped decidedly in recognizing and understanding the mosaic pattern of the occurring microsite conditions. It is suggested that interested workers agree on a standardized model of the Piche atmometer.—From auth. abstr.

SHANNON, JOHN W. 597

1966. Use of atmometers in estimating evapotranspiration. *In* Methods for Estimating Evapotranspiration. Irrig. and Drainage Spec. Conf., Las Vegas, Nev., Nov. 2-4, 1966. Amer. Soc. Civil Eng., N. Y., p. 109–130.

The California Department of Water Resources has during the past ten years collected extensive records of evaporation from Livingston black and white atmometers. Several separate studies have been made to determine the effect of various operational and environmental factors upon atmometer evaporation. Measurements of actual evapotranspiration have been made to correlate with the atmometer date. Though many questions still exist as to the differences between black and white atmometers in measurement of evaporation, it is concluded that this approach provides a reasonable means of estimating evapotranspiration of crops, particularly in undeveloped areas. —From auth. synop.

STANHILL, G. 598

1962. The use of the Piche evaporimeter in the calculation of evaporation. Roy. Meteorol. Soc. Quart. J. [London] 88(375): 80–82.

Water loss measured by the Piche evaporimeter, *E*, was found to be highly correlated with the calculated aerodynamic term, *Ea*, in Penman's evaporation formula. The error introduced by using the more convenient Piche evaporimeter measurements was less than that caused by the use of a single daily observation of vapor pressure in the calculation of the aerodynamic term. A test of a simplified form of Penman's formula, based on local Piche evaporimeter readings for the aerodynamic term and a regional value for the energy term, gave close agreement with the evaporation values calculated by use of the full formula.—From auth. sum.

VEIHMEYER, F. J., AND HENDRICKSON, A. H. 599

1957. Use of black and white atmometers for measuring the use of water by crops, evaporation and solar energy. *In* Third Congress on Irrigation and Drainage Trans., New Delhi, 1957. Int. Comm. on Irrig. and Drainage. [New Delhi] R27: 8.523–8.543, illus.

The results of studies on the use of water by crops and the evaporation difference between black and white Livingston atmometers give a high degree of correlation. Coefficients are given for several crops. These seem to be determined by the coverage of the ground by the crop and not to be dependent upon the kind of crop. Use of water by such different crops as alfalfa, walnuts, and tules gives almost the same coefficients.

The studies indicate that transpiration is not affected by changes in soil moisture until the latter is reduced to the permanent wilting percentage. In other words, the use of water by plants is influenced by climatic environment and not by the amount of readily available water in the soil.

The difference in evaporation between black and white atmometers has shown a high correlation with solar radiation as measured by an Eppley pyrheliometer.

The high correlation between evaporation from a white atmometer and that from a standard U.S. Weather Bureau pan suggests that the former could be substituted for the latter for the measurement of evaporation from a free water surface.

The difference in evaporation between black and white atmometers may be used as an indirect measure of water use by crops, provided the coefficient is known.—From auth. sum.

WARING, RICHARD H., AND HERMANN, RICHARD K. 600

1966. A modified Piche evaporimeter. Ecology 47(2): 308–310, illus.

A Piche evaporimeter is described that has only one evaporative surface, that is constructed from inexpensive plastic tubing, and from which water loss is measured gravimetrically. Such instruments were calibrated in the laboratory by controlling vapor-pressure deficits, and their precision was found adequate for many laboratory experiments.—From auth. abstr.

See also 512, 588, 679.

ESTIMATION OF EVAPOTRANSPIRATION FROM MEASUREMENT OF PHYSICAL FACTORS

Mass-Transfer or Profile Methods

BROOKS, F. A., GODDARD, W. B., AND MCDONALD, A. T. 601

1968. Analysis in transfers of energy, momentum and moisture near the ground. U. S. Army Electron. Command Atmos. Sci. Lab. Res. Div. Res. Develop. Tech. Rep. ECOM 66-G26-F, 57 p., illus.

The instrumentation efforts of the members of the Department of Agricultural Engineering, University of California, Davis, Calif., centered first on revising the evapotron made in Australia by W. B. Goddard and in constructing a second evapotron.

An intensive study was made of the dynamic behavior of the 50-ton floating shear-stress meter. A small error can occur in rapid changes of wind direction. This happens only in light variable winds, but further dynamic calibration is planned applying a sinusoidally variable force.

Only a start has been made on heat transfer by buoyant plumes or air parcels. This is a vital problem in reaching a real understanding of the micrometeorological system as a whole because in the lowest few hundred meters of the atmosphere there is an extraordinary change in flow regime. Beginning at the surface with purely frictional eddy transfers, there is a transition to almost wholly buoyant convective transfers. These large-scale circulation gusts then impinge on the frictional flow system close to the ground, distorting the profiles anticipated from wind-tunnel observations.

Much work remains to be done in analyzing the transfers of momentum, heat, and moisture near the earth's surface. Enlargement of profile formulas to include a transition height makes possible close fitting of observed profiles from which reliable gradients can be calculated, leading to more realistic determinations of eddy diffusivities.

There is a real need to tie in the flux/gradient interpretations of transfers with surface roughness and with direct measurements of turbulence intensity. A new experimental approach seems to be needed to develop better understanding of the role of buoyant air parcels in the micrometeorological systems of transfers of various entities.

This report summarizes much of the research covered in many other progress reports. See also Pruitt and Lourence (1968, 207).—From auth. introd. and sum.

CRAWFORD, T. V. 602

1965. Moisture transfer in free and forced convection. Roy. Meteorol. Soc. Quart. J. [London] 91 (387): 18–27.

The vertical transfer of moisture is examined under conditions in which the Richardson number varies from −2.5 to +2.9. The use of a nondimensional evaporative flux, similar to Priestley's non-dimensional sensible heat flux, and extensive data from the lysimeter site at Davis, Calif., show a smooth transition from forced to free convection. An equation for this transitional regime of mixed convection is derived by dimensional analysis and fitted to the data for different Richardson number ranges. A free convection interpretation of the data for $-2.5 < Ri < -0.025$ gives a proportionality constant of 1.40.

In stable conditions, the turbulent transfers are shown to decrease rapidly with increasing $+Ri$, and this behavior is consistent with some estimates of the initiation of decay of turbulence.—From auth. sum.

DALTON, JOHN 603

1799. Experiments and observations made to determine whether the quantity of rain and dew is equal to the quantity of water carried off by rivers and raised by evaporation; with an enquiry into the origin of springs. Manchester Lit. and Phil. Soc. Mem. 5: 346–372. [1798–1802]

A water balance was set up for several British watersheds. The difference between precipitation and runoff was felt to be water lost by evaporation. This was checked by the use of soil-filled pots 10 inches in diameter and 3 feet deep, equipped to measure runoff and percolation. Measured runoff and percolation were subtracted from rainfall. Dalton concluded that "the rain and dew of this country are equivalent to the quantity of water carried off by evaporation and by the rivers."

DALTON, JOHN 604

1801. Experimental essays on the constitution of mixed gases; on the force of steam or vapour from water and other liquids in different temperatures, both in a torricellian vacuum and in air; on evaporation; and on the expansion of gases by heat. Manchester Lit. and Phil. Soc. Mem. 5: 535–602. [1798–1802]

This classic statement of the principles of evaporation and vapor transfer is the basis of modern concepts of the physics of evaporation.

DYER, A. J. 605

1963. The adjustment of profiles and eddy fluxes. Roy. Meteorol. Soc. Quart. J. [London] 89(380): 276–280.

An assessment is made by use of simple diffusion theory of the rate of adjustment of profiles and eddy fluxes for (*a*) the leading-edge case as a function of distance and (*b*) the horizontally uniform case as a function of time. The solutions of the appropriate diffusion equations obtained by Philip (1959) are used as the basis of the calculations. For the leading-edge case the fetch-height ratio for 90 percent of the adjustment to be completed varies from 140 at a height of 0.5 meter to 530 at a height of 50 meters. The solution has application over a wide range of wind speed. For the case of horizontal uniformity and following an abrupt change in surface flux, 90 percent of the adjustment is completed in 0.45 minute at a height of 0.5 meter increasing to 86 minutes at a height of 50 meters.

It is suggested that these values indicate that the choice of site and conditions for micrometeorological research is critical and that disparity between a number of experiments may be a consequence of failure to satisfy the basic requirements of site and conditions.—From auth. sum.

DYER, A. J. 606

1965. The flux-gradient relation for turbulent heat transfer in the lower atmosphere. Roy. Meteorol. Soc. Quart. J. [London] 91(388): 151–157.

Data obtained during February and December 1962 at a carefully-chosen micrometeorological site at Kerang in northern Victoria, Australia, are used to examine the flux-gradient relation for sensible heat transfer.

DYER, A. J., HICKS, B. B., AND KING, K. M. 607

1967. The fluxatron—a revised approach to the measurement of eddy fluxes in the lower atmosphere. J. Appl. Meteorol. 6(2): 408–413.

As a result of experience gained with the evaporation in the measurement of eddy fluxes, a new instrument called the fluxatron has been developed. The computing efficiency has been improved by filtering out slow eddies which do not contribute to the eddy flux. The new instrument is extremely simple to operate in the field, and is thus suitable for use by relatively unskilled personnel.

In its present form, the fluxatron measures only sensible heat transfer. The measurement of the evaporative flux presents no difficulty in principle, but it is hoped that an alternative humidity sensor may be found other than a fine-wire wet bulb such as that in the evapotron.—From auth. abstr.

DYER, A. J., AND MAHER, F. J. 608

1965. The "evapotron": an instrument for the measurement of eddy fluxes in the lower atmosphere. Aust. C.S.I.R.O. Div. Meteorol. Phys. Tech. Pap. 15, 31 p.

The principles underlying the eddy correlation technique for the measurement of the vertical fluxes of heat and water vapor in the lower atmosphere are outlined. An instrument embodying these principles (the evapotron) is then described in detail, and the operational aspects of the technique are discussed.

The method consists of detecting, above the surface in question, the rapid fluctuations of temperature, humidity, and the vertical component of air velocity. The instantaneous multiplication of each of the first two parameters with the vertical component enables the vertical fluxes to be obtained by integration.

Wet- and dry-bulb thermometers employing very fine wire elements record the rapid fluctuations of temperature and humidity. A heated-wake anemometer, of unique design and also using fine wire elements, measures the vertical component of air velocity. From 400 c/s bridges, signals proportional to the relevant parameters are obtained by means of special circuitry. Multiplication and integration are carried out by modified watt-hour meters.

The electronic circuitry is completely transistorized and consumes 20 watts. Additionally, 30-80 watts are used by the heater of the anemometer. The sensors are normally placed at a height of 4 meters, but reduced heights can be used for measuring sensible heat transfer. The inability of the wet bulb to record the more rapid fluctuations near the ground prevents the satisfactory measurement of evaporation at reduced heights.

Energy balance measurements and comparisons with lysimeter observations demonstrate the validity of the method.—From auth. sum.

DYER, A. J., AND MAHER, F. J. 609

1965. Automatic eddy-flux measurement with the evapotron. J. Appl. Meteorol. 4(5): 622–625.

The evapotron, an instrument designed to measure vertical fluxes of heat and water vapor in the lower atmosphere, is described. Completely transistorized, the instrument consumes 50-100 watts and can be operated by a scientific technician. By means of an energy balance comparison, the accuracy of the instrument has been demonstrated to be within about 5 percent.—From auth. abstr.

DYER, A. J., AND PRUITT, W. O. 610

1962. Eddy-flux measurements over a small irrigated area. J. Appl. Meteorol. 1(4): 471–473.

During the summer of 1961, the vertical transfer of water vapor and sensible heat was determined at a height of 4 meters over an irrigated field at Davis, Calif. Simultaneous determinations of evaporation at the surface were obtained with a 20-foot weighing lysimeter, and the corresponding sensible heat transfer was computed by use of an energy balance approach.

A comparison of the two methods of determining these vertical fluxes showed excellent agreement early in the summer, but significant differences appeared as the season progressed. These could be attributed to severe contrasts developing between the heavily irrigated site and the surrounding areas, which, with no rain occurring, gradually dried out.

The fetch available was of the order 50-190 meters, depending on wind direction. The results clearly indicated that, under the conditions of this experiment, the vertical fluxes were not constant with height and a condition of horizontal uniformity did not exist.——Auth. abstr.

FITZPATRICK, EUGENE A. 611

1963. Estimates of pan evaporation from mean maximum temperature and vapor pressure. J. Appl. Meteorol. 2(6): 780–792, illus.

An equation for estimating pan evaporation has been derived by regression analysis from climatic data of a number of widely separated stations in Australia. The required data are mean maximum temperature, mean vapor pressure, and day length. The equation resembles the bulk aerodynamic (mass transfer) expression but does not contain a wind parameter.—From auth. abstr.

FRITSCHEN, L. J., AND VAN BAVEL, C. H. M. 612

1963. Evaporation from shallow water and related micrometeorological parameters. J. Appl. Meteorol. 2(3): 407–411.

During the spring of 1961, experiments were conducted at the U. S. Water Conservation Laboratory, Phoenix, Ariz., to measure the magnitude of evaporation from isolated shallow water and an extended area of shallow water and to measure related micrometeorological factors.—From auth. abstr.

GODDARD, W. B., AND PRUITT, W. O. 613

1966. Mass transfer—eddy flux method. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 42–44.

The Commonwealth Scientific and Industrial Research Organization of Australia developed an instrument, named the "evapotron," which uses the eddy flux method and is unique in its ability to independently measure sensible heat and evapotranspiration flux rates. An evapotron was brought from Australia to Davis, Calif., for use in a study of energy balances in relation to evapotranspiration.

GRIFFITHS, J. F. 614

1966. Another evaporation formula. Agr. Meteorol. [Amsterdam] 3(3/4): 257–261, illus.

This paper states that, although there are many equations connecting evaporation with climatic elements, a study shows that, over certain large areas of the Southwest, a very simple equation holds with adequate accuracy for practical purposes.

HARBECK, G. EARL, JR. 615

1962. A practical field technique for measuring reservoir evaporation utilizing mass-transfer theory. U. S. Geol. Surv. Prof. Pap. 272-E, p. 99–105, illus.

Expansion of the present program of evaporation measurement in the United States is practicable. The evaporation-seepage method can be used at a reasonable cost. The data required are wind speed at the 2-meter level in midlake, water-surface temperature in midlake, vapor pressure of the unmodified air, and change in lake stage. The change in stage is then separated into its two components, seepage and evaporation. A mass-transfer coefficient, N, can be determined for each reservoir for use in the equation $E = Nu_2 (e_o - e_a)$.

The energy-budget method, which requires much more expensive equipment and an elaborate data-processing and analysis procedure, can be reserved for measurements of evaporation from the larger lakes and reservoirs or from any reservoirs for which it may be impracticable to use the mass-transfer method because inflow and outflow cannot be measured with sufficient accuracy.—Auth. conclusion.

HARBECK, G. EARL, JR., KOHLER, MAX A, KOBER, GORDON E., AND OTHERS 616

1958. Water-loss investigations: Lake Mead studies. U. S. Geol. Surv. Prof. Pap. 298, 100 p., illus.

A comprehensive study to determine the evaporation loss from Lake Mead, Ariz. and Nev., was made during the period March 1952 to September 1953. Techniques of measuring evaporation that were tested during the course of an interagency cooperative investigation conducted at Lake Hefner, Okla., were used.

Evaporation from Lake Mead during the 1953 water year was determined by this investigation to be 875,000 acre-feet of water, equivalent to a depth of slightly more than 7 feet over the lake surface. Techniques were developed for the continuing determination of monthly evaporation from the reservoir.—From auth. abstr.

HORTON, ROBERT E. 617

1917. A new evaporation formula developed. Eng. News-Rec. 78(4): 196–199, illus.

This paper reports a revision of Dalton's formula for determination of evaporation.

KING, K. M. 618

1966. Mass transfer-profile methods. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 38–41.

We all take for granted that the concentration of water vapor decreases with increasing height above an evaporating surface. The problem discussed in this paper is the determination of evapotranspiration from observed vertical profiles of water-vapor concentration and other atmospheric variables. The upward flux of water vapor in the surface layer of the atmosphere is the resultant of turbulent diffusion working along a mean gradient of water-vapor concentration. The paper discusses various formulae for estimating the movement of water vapor upwards from the land surface and includes a full bibliography.—From. auth. sum.

MONIN, A. S., and OBUKHOV, A. M. 619

1959. Basic laws of turbulent mixing in the ground layer of the atmosphere. (Osnovnye Zakonomernosti Turbulentnogo Peremeshivaniya v Prizemnom Sloye Atmosfery. Akad. Nauk SSSR Geofiz. Inst. Tr. [Moscow] 1954, 24(151): 163–187.) Trans. by John Miller. OTS 59–15097. 31 p. 1959.

The article contains an analysis of the processes of mixing in a turbulent atmosphere, based on systematic application of the methods of the theory of similitude. Empirical data on the distribution of wind velocity under various conditions of temperature stratification are generalized, and a method is proposed for computing the austausch characteristics on the basis of measuring wind velocity and temperature gradient.—Tech Trans. 2: 250. 1959.

PASQUILL, F. 620

1962. Recent broad-band spectral measurements of turbulence in the lower atmosphere. J. Geophys. Res. 67(8): 3025–3031, illus.

PASQUILL, F. 621

1963. The determination of eddy diffusivity from measurements of turbulent energy. Roy. Meteorol. Soc. Quart. J. [London] 89(379): 95–106.

Two methods of deriving eddy diffusivity from measurements of turbulent energy are briefly reviewed, one based on the theory of the inertial subrange and therefore concerned with high-frequency energy and the other purely empirical and concerned with total energy. A third method, based on the statistical theory of diffusion of particles and concerned with low-frequency energy, is suggested.—From auth. sum.

PRIESTLEY, C. H. B., AND SHEPPARD, P. A. 622

1952. Turbulence and transfer processes in the atmosphere. Roy. Meteorol. Soc. Quart. J. [London] 78(338): 488–529.

RIDER, N. E. 623

1957. Water loss from various land surfaces. Roy. Meteorol. Soc. Quart. J. [London] 83(356): 181–193.

Daily water losses were evaluated from surfaces carrying crops of different size and shape which were transpiring at their potential rate.

RIDER, N. E., AND ROBINSON, G. D. 624

1951. A study of the transfer of heat and water vapor above a surface of short grass. Roy. Meteorol. Soc. Quart. J. [London] 77(333): 375–401.

STERN, W. R., AND FITZPATRICK, E. A. 625

1965. Calculated and observed evaporation in a dry monsoonal environment. J. Hydrol. [Amsterdam] 3(3/4): 297–311.

The annual regimes of calculated Penman evaporation, observed evaporation from the standard Australian tank and the Piche evaporimeters, and several empirical evaporation predictors from a dry monsoonal environment are described and compared. The relationship between the evaporation predictors and the Penman and tank evaporation is examined. This analysis was carried out with specific reference to selected wet and dry periods of the year, each period being of 100 days' duration.

It was found that evaporimeters and Dalton-type relations show a slight lag behind Penman evaporation and that the Thornthwaite and Blaney-Criddle estimates are inadequate to describe either the Penman or tank evaporation regime throughout the year in this climate. Marked differences in the efficiency of the various estimates in predicting Penman and tank evaporation over 5-day intervals were found. No single relationship could be identified that would satisfy both wet and dry periods of the year.

It is concluded that, in a dry monsoonal environment, the use of a single generalized relationship for predicting either Penman or tank evaporation from any of the predictors used can only be justified where a high degree of approximation is acceptable.—From auth. abstr.

SUOMI, V. E., AND TANNER, C. B. 626

1958. Evapotranspiration estimates from heat-budget measurements over a field crop. Amer. Geophys. Union. Trans. 39(2): 298–304, illus.

The heat-transfer processes which occur at the earth's surface have direct bearing on many of the physical problems in agriculture that relates to the plant environment. The evapotranspiration from a crop can be estimated from the disposition of solar and sensible energy available at the earth-air interface. A suitable measurement of the heat budget, including net radiation, heat transfer by soil conduction, air-temperature gradient above the crop, and vapor pressure gradient above the crop, will account for the fraction of solar energy used hourly or daily for evapotranspiration. A brief description of experimental equipment and some illustrative measurements are discussed in this paper.—From auth. abstr.

Compiler's Note.—See also King, Tanner, and Suomi (1956, 233).

SUTTON, O. G. 627

1934. Wind structure and evaporation in a turbulent atmosphere. Roy. Soc. Proc. Ser. A [London] 1946: 701–722.

A theory of the transfer of momentum and mass in a turbulent medium is developed. The theory is extended to the problem of evaporation on the assumption that the diffusion of mass follows the same laws as the diffusion of momentum.—From auth. sum.

SWINBANK, W. C. 628

1951. The measurement of vertical transfer of heat and water vapor by eddies in the lower atmosphere. J. Meteorol. 8(3): 135–145, illus.

Though the necessity of measuring the vertical fluxes of heat and water vapor, brought about by eddy movement in the lower atmosphere, has long been recognized, no direct method of determining these important quantities has previously appeared. The apparatus described in this paper provides a continuous record, over a 5-minute interval, of the detailed structure of tem-

perature, vapor pressure, and total wind speed and its vertical component, of the air passing a fixed point. It is possible to derive the required fluxes from such records, and the method of analysis is discussed in some detail. Specimen records and measurements of the fluxes are presented.—Auth. abstr.

TAYLOR, R. J. 629

1960. Similarity theory in the relation between fluxes and gradients in the lower atmosphere. Roy. Meteorol. Soc. Quart. J. [London] 86(367): 67–78.

TAYLOR, R. J., AND DYER, A. J. 630

1958. An instrument for measuring evaporation from natural surfaces. Nature [London] 181(4606): 408–409.

The Commonwealth Scientific and Industrial Research Organization of Australia recognized the need for a direct method of measuring evaporation from natural surfaces for application in a wide range of problems connected with agricultural science, hydrological engineering, and the like. The only method hitherto generally available has been that of isolating and weighing a portion of the evaporating body, a procedure which is cumbersome and often seriously interferes with the process it purports to measure. Reliance has, therefore, often been placed on formulae, usually of doubtful validity, relating evaporation with other meteorological variables.

Prototype equipment has been constructed which permits the automatic direct determination of natural evaporation by equating it to the vertical turbulent flux of water vapor in the layers of air near the ground.—From auth. introd.

See also 23, 25, 207, 389, 634, 677, 682-686.

Energy-Balance Methods

BOUCHET, R. J. 631

1963. Évapotranspiration réelle et potentielle signification climatique. *In* General Assembly of Berkeley, Aug. 19–31, 1963. Int. Union Geod. and Geophys. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 62: 134–142. [In French]

Solomon (1967, 660) thoroughly discusses this article.

BOWEN, I. S. 632

1926. The ratio of heat losses by conduction and by evaporation from any water surface. Phys. Rev. 27: 779–787.

It is shown that the process of evaporation and the diffusion of water vapor from any water surface into the body of the air above it is exactly similar to that of conduction or "diffusion" of specific heat energy from the water surface into the same body of air. Because of this similarity it is possible to represent the ratio R of heat loss by conduction to that by evaporation by the formula:

$$R = .46 \left(\frac{T_w - T_a}{P_w - P_a}\right) \frac{P}{760}$$

where T_a and P_a are the original temperature and vapor pressure of the air passing over a lake, and T_w and P_w are the corresponding quantities for the layer of air in contact with the water surface. [P is the air pressure.] The substitution of R times the evaporation loss for the value of the conduction heat loss in the Cummings equation for evaporation makes it an exact equation for the determination of evaporation from any water surface in terms of net radiant energy absorbed by the water and the heat stored in the water.—Auth abstr.

BROWN, KIRK W., AND COVEY, WINTON 633

1966. The energy-budget evaluation of the micrometeorological transfer processes within a cornfield. Agr. Meteorol. [Amsterdam] 3(1/2): 73–96, illus.

BUDYKO, M. I. 634

1958. The heat balance of the earth's surface. (Teplovoi balans zemnoi poverkhnosti. Gidrometeorol. izdatel'stvo [Leningrad] 1956.) Trans. from the Russian by Nina A. Stepanova. U. S. Weather Bur. PB131692, 259 p.

This monograph summarizes the results of investigations in heat balance climatology of the earth's surface. Various methods for determining the components of the heat balance are analyzed and systematized. Data on geographical distribution of all components of the heat balance and of their annual and diurnal variations are presented. Applications of the heat balance climatology to various problems of physical geography, agrometeorology, and hydrology are interpreted. The utilization of heat balance data for the analysis of meteorological effectiveness of ameliorative measures is investigated.—From auth. annot.

CUMMINGS, N. W. 635

1936. Evaporation from water-surfaces: Status of present knowledge and need for further investigations. Amer. Geophys. Union Trans. 17(2): 507–509.

CUMMINGS, N. W. 636

1940. The evaporation-energy equations and their practical application. Amer. Geophys. Union Trans. 21(2): 512–522, illus.

CUMMINGS, N. W., AND RICHARDSON, BURT 637

1927. Evaporation from lakes. Phys. Rev. 30(4): 527–534.

Evaporation can be determined by the aid of the first law of thermodynamics in such a way that wind velocity need not enter the calculation. Air temperature and humidity enter only as terms in a correction which can have a relatively small average value under typical conditions. The complete equation is:

$$E=(H\text{-}S\text{-}C)/L(1+R)$$

where E is the evaporation, H the difference between the incoming and outgoing radiation, S the heat stored in a column of water having unit cross-section, C a correction for heat carried by flowing water and leakage of heat through the walls of the vessel, L the latent heat of water, and R Bowen's ratio. A method of finding the difference between the incoming and outgoing radiation by means of observations on a well insulated pan is described, and also a method of finding the ratio of sensible heat to latent heat transmitted through the air-water surface. Bowen's theoretical conclusions respecting this ratio were found to be consistent with observations.

The above formula can be used in estimating evaporation from an actual lake whenever the requisite data can be obtained. Although from a physical standpoint the quantity of sensible heat passing through the air-water surface is not strictly negligible, nevertheless, in most meteorological and engineering applications, the error caused by neglecting this quantity will be negligible in comparison with other errors that enter the main problem of which evaporation is a part.—Auth. abstr.

EKERN, PAUL C. 638

1965. The fraction of sunlight retained as net radiation in Hawaii. J. Geophys. Res. 70(4): 785–793, illus.

Both estimated and measured values of net radiation over several different surfaces established the retention of approximately two-thirds of the sunlight as net radiation for stations at low elevations in Hawaii. This high re-

tention of sunlight was a consequence of both low reflectance and a very low heating coefficient (change of long wave net radiation with change in total net radiation). The persistent high elevation of the sun and the efficient convective heat sink formed by the maritime air helped to account for this large retention of sunlight as net radiation. The mineralogic composition of the soil and the leaf habit of the vegetative cover contributed to the low reflectance from these surfaces. Since this net radiation can be used to heat the soil, plants, and air, and to evaporate water, the heat and moisture budgets of a surface in the maritime tropics may differ markedly from those of a surface in the temperate latitudes under similar solar radiation.—Auth. abstr.

EKERN, PAUL C. 639

1965. Disposition of net radiation by a free water surface in Hawaii. J. Geophys. Res. 70(4): 795–800, illus.

Temperate latitudinal expressions such as the Dalton and Penman formulations predict class *A* pan evaporation though certain of the constants seemed unique for the tropics. Air temperature alone was not a sensitive index of evaporation. The winter rate of pan evaporation supports the contention that a large fraction of sunlight is converted to net radiation. The seasonal shift in the fraction of sunlight used for pan evaporation responded to the seasonal shift in net radiation, but also included was the effect of strong positive advection of heat from the surroundings, particularly in the summer. Pineapple planted upwind from the pan served as a dry fetch. Evaporation measured by atmometer followed convectional patterns, with the black Bellani plate as the best index of sunlight and pan evaporation.—Auth. abstr.

FITZPATRICK, E. A., AND STERN, W. R. 640

1965. Components of the radiation balance of irrigated plots in a dry monsoonal environment. J. Appl. Meteorol. 4(6): 649–660.

Over irrigated crops of cotton grown in a dry monsoonal environment, net radiation was measured daily over a period of one year together with total radiation, duration of sunshine, and wet and dry bulb screen temperature. Daily estimates of total, effective terrestrial, and net radiation were obtained from several empirical relationships, and these were compared with measured values.—From auth. abstr.

FRITSCHEN, L. J. 641

1965. Accuracy of evapotranspiration determinations by the Bowen ratio method. Int. Ass. Sci. Hydrol. Bull. [Louvain] 10(2): 38–48, illus.

Evapotranspiration rates determined from meteorological data by the Bowen-ratio method were tested against rates obtained from weighing lysimeters. The tests were conducted on an irrigated field (73 by 92 m.), where the minimum fetch was 27 m. Air-temperature and vapor-pressure differences obtained as 15-minute averages at heights of from 5 to 40 cm. above the crop surface were used to calculate evapotranspiration. The results indicate that the Bowen ratio method can be used successfully to determine the evaporative flux for short periods, which can be summed for longer periods. During daylight periods, the absolute errors were less than 0.02 cal. $cm.^{-2}$ $min.^{-1}$ (or ly $min.^{-1}$), while the relative errors were less than 5 percent.—Auth. abstr.

FRITSCHEN, LEO J. 642

1966. Evapotranspiration rates of field crops determined by the Bowen ratio method. Agron. J. 58(3): 339–342.

Simultaneous evapotranspiration rates were determined biweekly for the crop combinations of alfalfa and barley, alfalfa and cotton, alfalfa and sor-

ghum, wheat and oats, and cotton from meteorological data by the Bowen method. The crops were grown under irrigated conditions in the hot, arid region of south central Arizona. Calculated evapotranspiration rates ranged from 1.0 to 1.8 times net radiation, indicating that large amounts of energy were extracted from the air mass.

The Bowen-ratio method can be used as a survey technique or continuous sampling method to obtain short-period evapotranspiration rates under field conditions. It appears to be one of the few methods which will yield valid results when crops are subjected to frequent and heavy irrigation or where water tables are present.—From auth. abstr.

FRITSCHEN, LEO J. 643

1966. Energy balance method. *In* Evapotranspiration and Its Role in Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5–6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 34–37, illus.

Meteorological methods in general have several distinct advantages for determining evaporation and transpiration from natural or cultivated surfaces. These methods, generally nondestructive, can be used where other methods fail (i.e., over widely-spaced desert vegetation, rocky soils, and where plants have very deep root systems), they are capable of yielding relatively accurate short period rates, and they supply part of the meteorological information necessary for understanding the results; moreover, the instruments used in meteorological methods can be constructed so that the methods can be employed with a great deal of mobility.

Meteorological methods also have disadvantages. They are not integrating and require continuous measurement of several parameters (some of which are difficult to measure), the nature of the equations and parameters requires repeated solution rather than the use of long-period averages, the initial costs of sensors and recording equipment are quite high, and the basic assumptions of the methods may not be met under the conditions of interest.

The energy-balance method utilizing the Bowen ratio has been used to determine evaporation from agricultural surfaces. Results of tests under humid and arid conditions indicate that the method will yield valid results if the basic assumptions are met. The surface in question must be homogeneous and suitable for sampling. Indications are that 1-m. spacing of crops such as cotton, sorghum, and corn yields a homogeneous surface, while 2 x 2 skip-row spacing does not.

The main concern with this method is the assumption of vertical fluxes, i. e., no horizontal divergence of fluxes between the surface and points of measurement. To assure at least 90 percent profile modification at 40 cm. above the surface, a fetch of 53 m. or a fetch-height ratio of 132 is required. More fetch and larger ratios are necessary at greater heights; i.e., at a height of 2 m., a fetch of 420 m., or a ratio of 210, is required.

The required differences in air temperature and vapor pressure should be measured as close to the surface as possible to reduce the fetch requirements. The gradients are larger and easier to measure near the surface. However, the variability of most agricultural surfaces necessitates spacial sampling when sensors are placed close to the surface,

Since calculated evaporation is directly related to net radiation and soil-heat flow, proper measurement of these phenomena is necessary. Omission of soil-heat flow could lead to serious errors.—From auth. sum.

FRITSCHEN, LEO J. 644

1967. Net and solar radiation relations over irrigated field crops. Agr. Meteorol. [Amsterdam] 4(1): 55–62.

Many of the meteorological methods used to estimate evapotranspiration from crop surfaces require net radiation information. Since net radiation data are not generally available and solar radiation is measured at several locations throughout the world, it would be desirable to estimate net radia-

tion from solar radiation. Consequently, a relation was sought between solar radiation and net radiation measured over irrigated field crops of alfalfa, barley, wheat, oats, cotton, and sorghum.

When the data for all crops and all days were pooled and analyzed by linear regression, the resulting standard error was 0.06 ly/min. Thus, estimating net radiation for any of the crops from solar radiation would result in a standard error of 38 ly, or approximately 10 percent, for a 12-hour day having 649 ly incoming radiation. The regression equation may be solved by using either hourly or daily solar radiation data.

In the absence of net radiation data, either the pooled regression or the individual crop regressions may provide sufficiently accurate estimates for some applications—for example, estimating evapotranspiration to be used in the design of irrigation projects. However, the error appears to be too large where daily evapotranspiration results are required. Therefore, measurements of net radiation are still desirable.—From auth. sum.

FRITSCHEN, LEO J. 645

1970. Evapotranspiration and meteorological methods of estimation as applied to forests. *In* Third Forest Microclimate Symposium Proc., Seebe, Alberta, Sept. 23–26, 1969. Canadian Forestry Service [Calgary, Canada] p. 8–27.

The energy balance of a surface is a dynamic balance. Altering one term causes the rest to change. Since the evaporation process is the largest heat sink, small changes in the evaporation rate cause relatively large changes in the other terms. Sample energy balances over free water, bare soil, and plant surfaces are presented to illustrate the effect of soil drying, plant height, and wind speed upon the evaporation rate.

Evapotranspiration can be estimated by a meteorological method. The basic assumptions of the commonly used meteorological methods are listed and discussed with respect to their application in forestry. A resulting conclusion is that the combination of the energy balance and eddy correlation techniques may be the most suitable method for determining evapotranspiration from forests.—Auth. abstr.

FRITSCHEN, LEO J., AND VAN BAVEL, C. H. M. 646

1962. Energy balance components of evaporating surfaces in arid lands. J. Geophys. Res. 67(13): 5179–5185, illus.

The components of the surface energy balance equation were determined during April and May 1961 in experiments conducted over an extended wet, bare soil surface and over an area of shallow water in the vicinity of Phoenix, Ariz. Evaporative flux measurements were determined from sensitive weighing lysimeters. Net radiation was measured with miniature net radiometers. Soil heat flux was measured with heat-flow transducers. The change in energy storage of the layer of soil or water above the heat-flow transducer was computed; direct measurements of soil or water temperature were used. The sensible heat flux into the air was determined by solving the energy balance equation. The results of triplicate measurements made every 15 minutes for 9 consecutive days indicate that the daily totals of sensible heat flux into the air were generally negative, that is, away from the surface. The rate of evaporation was larger from a wet soil surface than from a free water surface. On days of similar solar radiation, the evaporative flux tended to be correlated with wind speed.—Auth. abstr.

FRITSCHEN, LEO J., AND VAN BAVEL, C. H. M. 647

1964. Energy balance as affected by height and maturity of sudan grass. Agron. J. 56(2): 201–204.

Evapotranspiration rates of 75-cm.-high and 100-cm.-high crops of sudangrass were similar and considerably larger than those of 140-cm.-high crops of sudangrass. The difference appeared to be due to the presence of seed-

heads rather than physiological maturity. For days of similar energy input, evapotranspiration increased with wind speed. These facts emphasize the point that for well-watered sudangrass, physical rather than physiological factors regulated the evapotranspiration.—From Auth. synop.

GERBER, J. F., AND DECKER, W. L. 648

1960. Estimates of Bowen's ratio by the heat budget measurements of a cornfield. J. Geophys. Res. 65(11): 3699–3702.

Estimates of Bowen's ratio, which is the ratio of the amount of heat transferred as sensible heat to that transferred as latent heat from a surface, were made from a 10-acre cornfield during the summer of 1959. These estimates were based on a heat budget technique which partitioned the energy used in evaporative processes, sensible heat transfer to the atmosphere, and heat exchange to the soil. The cases investigated could be divided into two groups. One group of ratios was associated with wet soil surfaces, and the modal value of the ratio was 0.05. The second group of ratios was associated with dry soil surfaces, and a modal of 1.65 was noted. Under practical agronomic conditions the larger values of the ratio are advantageous, since this condition provides for a more economical use of water.—Auth. abstr.

HALSTEAD, MAURICE H., AND COVEY, WINTON 649

1957. Some meteorological aspects of evapotranspiration. Soil Sci. Soc. Amer. Proc. 21(5): 461–464.

Increasing attention has been given to various equations of an engineering type designed to estimate, from available climatic data, the amount of water used by plants. Some of the basic assumptions involved in these equations are examined in the light of recent advances in knowledge of the physical processes at the earth-atmosphere interface.

It is found that the majority of equations involving the concept of potential evapotranspiration or consumptive use of water tend to assume a homogeneous soil-moisture regime infinite in horizontal extent. Therefore, it has been difficult to apply these equations to irrigation practice, which obviously must create isolated areas of above normal moisture. Consequently, the problem is approached from the strictly physical point of view, and it is shown that a solution can be obtained, provided that sufficient knowledge of soil interactions is available.—From auth. abstr.

HOLZMAN, BENJAMIN 650

1941. The heat-balance method for the determination of evaporation from water-surfaces. Amer. Geophys. Union Trans. 22(3): 655–660.

The heat-balance method for determining evaporation from water-bodies is known to be theoretically precise. However, the difficulties to be encountered in accurately measuring most of the essential parameters in the heat-balance equation appear to invalidate the practical usefulness of this technique.

A direct determination of evaporation by using measurements of humidity and wind-gradient in the turbulent atmosphere is suggested.—Auth. conclusion.

JENSEN, MARVIN E., AND HAISE, HOWARD R. 651

1963. Estimating evapotranspiration from solar radiation. Amer. Soc. Civil Eng. Proc., J. Irrig. and Drainage Div. 89(IR4): 15–41, illus.

Recent studies throughout the world have shown the evapotranspiration (consumptive use) in humid and semihumid areas can be predicted on a daily basis, as well as for shorter time periods, by using an energy balance approach. To facilitate the application of energy-balance concepts to semi-arid and arid areas, measured evapotranspiration data from irrigated areas

in the Western United States, obtained during the past 35 years, were collected, reevaluated, and combined with estimates of solar radiation. Approximately 1,000 measurements of evapotranspiration for individual sampling periods for various crops were found usable. The results of this study provide mean numerical values to use in a dimensionless energy-balance equation for predicting evapotranspiration.

A brief review of the energy-balance concept is presented, with a tabular summary of mean measured ratios of evapotranspiration to solar radiation. The ratio represents the combined effects of reflectance or albedo and relative effects of effective thermal radiation, sensible heat flux to the soil and air, and other minor components at various stages of crop growth. Procedures and examples are given to permit estimates of evapotranspiration to be made for various crops.—From auth. synop.

KING, K. M. 652

1961. Evaporation from land surfaces. *In* Symposium on Evaporation, Toronto, Canada, 1961. Canada Dep. N. Aff. and Nat. Resour., Water Resour. Br., Hydrol. Symp. Proc. [Ottawa] 2: 55–82.

Evapotranspiration from a land surface depends primarily on the radiant energy supply to the surface but may be limited by the rate of movement of water to the evaporation surface. Those characteristics of plants and soils which affect their capability to limit evapotranspiration are described. Under summer conditions, without rainfall, the evaporation from an originally moist bare soil decreases more rapidly than does the transpiration rate from the same area completely covered with vegetation. For the intermediate case of a noncomplete vegetative cover, the rate of decrease of evapotranspiration upon drying depends upon how much of the total energy supply reaches the soil surface as well as upon the soil characteristics. A description is given of the instrumentation for and the results from an experiment in which the energy balance and evapotranspiration for a cornfield were simultaneously measured.—Auth. synop.

LEE, RICHARD 653

1963. Evaluation of solar beam irradiation as a climatic parameter of mountain watersheds. Colo. State Univ. Hydrol. Pap. 2, 50 p., illus.

To express the water balance quantitatively for natural hydrologic units, an energy budget approach to evapotranspiration losses is most promising. Potential insolation—a fundamental measure of the flux of energy upon the earth's atmosphere—is the major component of the energy exchange; its efficient evaluation as a function to topographic exposure has required the development of new techniques.

This paper shows that, with respect to the incident of direct solar energy, topography has its greatest influence in the middle latitudes. The importance of slope orientation and steepness at 40° north latitude is evaluated in detail. The construction and use of a new "topographic sampler"—developed to facilitate topographic sampling from contour maps—are explained (Lee, 1963, 654).

Insolation-streamflow comparisons on 12 experimental watersheds indicate that, in many instances, there may be an excellent correlation between the potential energy incident upon an area and evapotranspiration losses.—From auth. abstr.

LEE, RICHARD 654

1963. The "topographic sampler." J. Forest. 61(12): 922–923, illus.

The analysis of mountainous landscapes with respect to slope steepness and orientation is a laborious task. This paper describes a simple instrument that expedites the procedure. Details of design and application are given.—Auth. abstr.

LEE, RICHARD 655

1964. Potential insolation as a topoclimatic characteristic of drainage basins. Int. Ass. Sci. Hydrol. Bull. [Louvain]. 9(1): 27–41, illus.

A method is derived for characterizing drainage basins and other land areas in terms of their "average" exposure and potential irradiation by the sun. The most efficient trigonometric and graphical procedures for evaluating potential insolation upon sloping surfaces are selected, and the concept of a "theoretical intercepting surface" is employed to describe terrain elements in terms of a single-valued facet.

Applications with secondary experimental data indicate that there is a strong positive correlation between derived "radiation indexes" and evapotranspiration as measured by the precipitation-runoff difference.—Auth. abstr.

LEMON, EDGAR 656

1963. Energy and water balance of plant communities. *In* Environmental Control of Plant Growth. Symp. Proc., Canberra, Australia, Aug. 1962. Evans, L. T. (ed.). Academic Press, New York and London p. 55–78.

SARGEANT, D. H., AND TANNER, C. B. 657

1967. A simple psychrometric apparatus for Bowen ratio determinations. J. Appl. Meteorol. 6(2): 414–418.

A simple apparatus has been devised which automatically reverses the vertical positions of two pairs of shielded and aspirated wet- and dry-bulb diodes. Analog voltage signals proportional to the dry- and wet-bulb temperatures T and T_w and to the differences $\triangle T$ and $\triangle T_w$ are provided. The diodes present a low source impedance, a linear response over normal ranges, a sensitivity of about 2.3 $mV(^\circ C)^{-1}$, and as used here, a time constant of about 1 minute. From these measurements the Bowen ratio can be determined conveniently.—Auth. abstr.

SELLERS, WILLIAM D. 658

1964. Potential evapotranspiration in arid regions. J. Appl. Meteorol. 3(1): 98–104, illus.

In this paper the concept of potential evapotranspiration as applied to arid regions is examined; an energy balance approach suggested by Budyko is used. By use of data for Yuma, Ariz., it is shown that a 50 percent increase in the relative humidity of the air above an irrigated field is accompanied by a 10 to 15 percent decrease in potential evapotranspiration, a negligible decrease in the net radiation, and a temperature increase of the surface relative to the air of 2 to 3° C.

The estimated annual potential evapotranspiration at Yuma is about 2000 mm., which is 30 to 50 percent higher than estimates based on Thornthwaite's method.—From auth. abstr.

SELLERS, WILLIAM D., AND HODGES, CARL N. 659

1962. The energy balance of non-uniform soil surfaces. J. Atmos. Sci. 19:482–491.

A "fluxometer" has been developed for estimating the fluxes of latent and sensible heat from bare soil and short grass in any type of terrain. The fluxometer consists of two polyethylene-covered tunnels 50 cm. long, 30 cm. wide, and 6 to 12 cm. high. The floor of one is exposed to the soil surface; the floor of the other is covered with plastic, as a control. The latent and sensible heat fluxes can be determined from the wet- and dry-bulb temperatures of the air entering and leaving the exposed tunnel at a known rate.

A comparison of hourly evaporation rates measured simultaneously with the fluxometer and with three precision weighing-type lysimeters near Phoe-

nix, Ariz., showed that the fluxometer usually gave lower evaporation rates than the lysimeters.

A second experiment was conducted in a dry river channel in southeastern Arizona. Evaporation rates were measured during 18 days and agree well with estimates by other investigators. For 33 hourly periods, during which all energy balance components were measured, the average absolute error was 2.4. ly hr.$^{-1}$; the average relative error was 11.0 percent.—From auth. abstr.

SOLOMON, S. 660

1967. Relationship between precipitation, evaporation, and runoff in tropical-equatorial regions. Water Resour. Res. 3(1): 163–172, illus.

Bouchet's theory [1963, 631] on actual and potential evaporation can be used as a basis to develop semi-empirical relationships between precipitation, actual evaporation, and radiation. These relationships are curvilinear, and the derived precipitation-runoff relationships are also curvilinear. Since the variation of annual radiation from one year to another in tropical-equatorial regions is not very significant, the average value of annual radiation can be approximated by use of direct measurements or indirect estimates from data taken over a period of from 2 to 5 years. This value can be used with the semi-empirical relationship developed in the paper to obtain fair estimates of the annual variation of actual evaporation and runoff from data on annual precipitation and good estimates of the long-term averages of these hydrologic characteristics. Bouchet's theory can be used to analyze evaporation and runoff for periods of less than 1 year and for estimating lake and reservoir evaporation. However, in this case, the assessment of the effect of heat and moisture storage requires further investigation.—Auth. abstr.

TANNER, C. B. 661

1957. Factors affecting evaporation from plants and soils. J. Soil Water Conserv. 12(5): 221–227, illus.

In this paper, the author discusses some of the factors that affect the amount of evaporation and transpiration and the manner in which they operate.

TANNER, C. B. 662

1960. A simple aeroheat budget method for determining daily evapotranspiration. *In* Int. Cong. Soil Sci. Trans. (7th) Madison, Wisc., 1960. Elsevier Pub. Co. [Amsterdam] 1: 203–209.

TANNER, C. B. 663

1960. Energy balance approach to evapotranspiration from crops. Soil Sci. Soc. Amer. Proc. 24(1): 1–9, illus.

The vertical energy balance yields reliable estimates of evapotranspiration on an hourly (or half-hourly) basis under large variations of thermal stratification, provided the measurements are made close to a reasonably homogeneous surface and provided suitable spacial and time-sampling procedures are followed.—From auth. abstr.

TANNER, C. B. 664

1963. Energy relations in plant communities. *In* Environmental Control of Plant Growth. Symp. Proc., Canberra, Australia, Aug. 1962. Evans, L. T. (ed.). Academic Press, New York and London, p. 141–148.

TANNER, C. B., AND LEMON, E. R. 665

1962. Radiant energy utilized in evapotranspiration. Agron. J. 54(3): 207–212, illus.

This paper evaluates the amount of radiant energy utilized in evapotrans-

piration under field conditions and briefly considers the radiation balance, the various components of the energy balance and their relative magnitudes, and the crop and soil factors influencing the amount of the net radiation exchange utilized in evapotranspiration. Data presented show that, when soil moisture is available and a substantial crop cover shades the ground, most of the net radiation is used in the evapotranspiration process.—Auth. synop.

TROMBLE, J. M., AND SIMANTON, J. R. 666
1969. Net radiation in a riparian mesquite community. Water Resour. Res. 5(5): 1139–1141.

Net radiation patterns for a riparian mesquite community are similar to net radiation patterns obtained for a humid forest. The net radiation peak of the open area was 61 percent of the net radiation peak above the canopy. The net radiation within a mesquite canopy peaked 9 percent higher but had a lower daily total value than the radiation above the canopy. The differences in net radiation peaks were attributed to differences in the canopy geometry, solar position, and surface reflectance, whereas differences in daily net radiation were attributed to differences in surface reflectance characteristics.—Auth. abstr.

VAN BAVEL, C. H. M., AND FRITSCHEN, L. J. 667
1965. Energy balance of bare surfaces in an arid climate. *In* Methodology of Plant Eco-Physiology. Montpellier Symp. [Montpellier, France, 1962] Proc. UNESCO Arid Zone Res. [Paris] 25: 99–107, illus.

The disposition of radiant energy at the surface of the earth in an arid environment is a matter of continuing interest. Rainfall or irrigation and the events that follow are a drastic change from prevailing conditions and may have important implications for the physical eco-system. Recently initiated studies at the U.S. Water Conservation Laboratory near Phoenix, Ariz., are concerned with the energy balance at the surface in an arid environment. Interest is focused on conditions that are typical for irrigated land. The investigations are conducted in the midst of the Salt River Valley, which is irrigated both with surface water supplies and with water pumped from underground reservoirs.

In this article a description is given of instrumentation used in investigations of the surface energy balance, and some typical data are presented and discussed, one set pertaining to a day on which the surface was very wet and another one to a day on which the surface was relatively dry. On both days of observation conditions were typical for an arid climate; that is, there was a cloudless sky, a high radiation level, high temperatures, and a low moisture content of the air.—From auth. sum.

WEBB, E. K. 668
1964. Further note on evaporation with fluctuating Bowen ratio. J. Geophys. Res. 69(12): 2649–2650.

See also 5, 23, 25, 207, 208, 263, 371, 372, 378, 437, 507, 573, 677, 681–686.

The Problem of Advection

BENNETT, IVEN, AND NELSON, RONALD A. 669
1960. The nighttime influence of irrigation on desert humidities. U. S. Army Quartermaster Res. and Develop. Center Environ. Protect. Res. Div. Tech. Rep. EP-136, 42 p., illus.

Field observations were made in and around the Yuma oasis of southwestern Arizona during the summer of 1956 to examine the role of irrigated farmland in modifying the nighttime humidity of desert air. A moderate increase was observed in moisture content of the air in the oasis compared with desert air. The magnitude of the increase was related to the general

moisture and to the two prevailing summer air masses; with dry Pacific air the increase in dewpoint amounted to 15° to 20° F. and with moist air from the Gulf of Mexico it was limited to 5° to 10° F.

Advection of moist air from the oasis into the desert could not be sharply delimited quantitatively, but within the first few hundred yards from the edge of the oasis, advection diminished rapidly, and it seemed barely evident at one mile.—From auth. abstr.

DODD, ARTHUR V., AND MCPHILIMY, HARRY S. 670

1959. Yuma summer microclimate. U. S. Army Quartermaster Res. and Eng. Center Environ. Protect. Res. Div. Tech. Rep. EP-120, 34 p., illus.

Detailed and continuous temperature, wind, and radiation records for a 2-month summer period under diverse terrain conditions at Yuma Test Station, Ariz., were analyzed. It was found that the temperature regime near and at the earth's surface varies significantly from the regime as found by "standard" observations. Midday temperatures greater than 140° F. were frequent on both sand and desert pavement surfaces. Temperatures at levels 200 cm. above these surfaces were seldom more than 110° F.

The total incoming radiation at Yuma Test Station at midday is extremely high, often exceeding 500 BTU/Ft.^{2}/hr. Outgoing radiation is also at a maximum at midday, when it averages over 300 BTU/Ft.^{2}/hr. The net radiation is positive (incoming) for an average of 12 hours each day and exceeds 150 BTU/Ft.^{2}/hr. for an average of 6 hours each day. At night there is a small negative radiation balance.—From auth. abstr.

HAND, D. W. 671

1964. Advective effects on evaporating conditions as hot dry air crosses irrigated lucerne. Empire J. Exp. Agr. [London] 32(128): 263–273.

Evaporimeter and psychrometer studies have established that there was an edge effect, due to the lateral transfer of energy, as a hot, dry wind blew across a field of irrigated lucerne [alfalfa] in the Northern Sudan, for a distance of 60 meters in the downwind direction. Stomatal studies indicated that there was a change in the pattern of behaviour over a similar downwind distance.—Auth. sum.

MILLAR, B. D. 672

1965. Effect of local advection on evaporation rate and plant water status. Aust. J. Agr. Res. [Melbourne] 15(1): 85–90, illus.

The effects of local advection on the evaporation rate and the relative turgidity of Ladino clover grown in lysimeters were measured at four distances downwind from the leading edge of a small irrigated field adjoining a drier area.

Both the evaporation rate and the relative turgidity decreased with increasing distance downwind from the leading edge and were directly proportional to powers of the downwind dimension. Presumably plant growth rate may also depend on the distance downwind.

Plants near the leading edge showed early afternoon wilt during a mild day in autumn, although soil moisture content was very high. This is in keeping with the concept of a "ceiling absorption rate". Some agronomic implications of these advective effects are discussed—From auth. sum.

NIXON, P. R., AND LAWLESS, G. P. 673

1968. Advective influence on the reduction of evapotranspiration in a coastal environment. Water Resour. Res. 4(1): 39–46, illus.

Incoming air from an ocean may either supply heat to a land area or serve as an energy sink. A marked example of the energy sink phenomenon occurs in a coastal valley of California. Advective cooling resulted in much lower evapotranspiration than amounts reported for interior locations during the

two months studied, July and September. Evapotranspiration from irrigated ryegrass was equivalent to about two-thirds of net radiation on clear days. This ratio is lower than the ratios of 8/10 or 9/10 commonly observed in humid interior areas and is much lower than ratios reported for interior desert conditions. Overcast days having low net radiation did not produce amounts of evapotranspiration that were proportionally as low. This observation indicated that there was a trade off between radiation and advection under these coastal conditions where a critical balance existed between air and surface temperatures.—Auth. abstr.

OHMAN, HOWARD L., AND PRATT, RICHARD L. 674

1956. The daytime influence of irrigation upon desert humidities. U. S. Army Quartermaster Res. and Develop. Center Environ. Protect. Res. Div. Tech. Rep. EP-35, 30 p., illus.

This report describes a study of daytime dewpoint distribution within and about the irrigated farmland near Yuma, Ariz. A comparison was made of the moisture content of the air before, during, and after passage over irrigated land; data obtained during the course of a field investigation in the summer of 1954 were used. The pattern of dewpoint distribution was sampled through observations taken within and about fields of selected crops in various stages of growth.

The results of the study indicate that evaporation and transpiration cause an average increase of 6° to 8° F. in the dewpoint of the air directly over an irrigated area but that the lateral extent of this effect is limited to distances of 100 feet or less from the fields. The influence of irrigation agriculture upon humidities in the various testing sites within Yuma Test Station, therefore, is negligible.—From auth. abstr.

PHILIP, J. R. 675

1959. The theory of local advection: I. J. Meteorol. 16(5): 535–547.

This paper provides an introduction to the practical implications and physical basis of local advection, but it is mainly devoted to developing methods of analysis for application in later papers. The study on which the paper reports aims to provide simple and rapid numerical procedures for the solution of advection problems.

RIDER, N. E., AND PHILIP, J. R. 676

1960. Advection and evaporation. *In* General Assembly of Helsinki, July 25-Aug. 6, 1960. Int. Ass. Sci. Hydrol. Pub. [Gentbrugge] 53: 421–427.

Advection is defined as the exchange of energy or moisture due to horizontal heterogeneity in conditions at the earth's surface. Thus advection influences the energy and moisture balance of evaporating surfaces when these are adjacent at surfaces of a different character.—From. auth. abstr.

See also 25, 185, 207, 532–534, 589, 658, 667, 681.

EVALUATION OF VARIOUS MEASUREMENT AND PREDICTION METHODS FOR ESTIMATING WATER LOSSES

BOGARDI, MAGDA ETHEL 677

1966. Estimation of evaporation and evapotranspiration from climatic data. Master's thesis, Agr. Eng. Dept., Colo. State Univ., Fort Collins, Colo. 85 p., illus. Processed

This thesis summarizes many methods that have been developed for use in studying evaporation and evapotranspiration. It includes discussions of the processes of evaporation, transpiration, and evapotranspiration and the

factors that influence each. In considering direct measurement of evapotranspiration, the thesis discusses field experimental plots, soil-moisture depletion studies, integration method, inflow-outflow method for large areas, tank and lysimeter experiments, and nutrient solution experiments.

Many empirical formulae for estimating evaporation and evapotranspiration are discussed, as well as formulae based on considerations of vapor transport and the energy balance.

CALIFORNIA DEPARTMENT OF WATER RESOURCES 678

1963. Vegetative water use studies 1954-1960. Resour. Agency of Calif. Bull. 113, 121 p., illus.

This report presents data on vegetative consumptive use of water, or evapotranspiration, together with certain interrelationships with agricultural climatic factors influencing such use. The findings summarized cover the period 1954–60 and represent many individual measurements of evapotranspiration and related agricultural climatic data. The measurements of evapotranspiration represent scores of soil samples, neutron probe readings, and evapotranspirometer measurements of irrigated alfalfa, pasture, plums, cotton, and grass crops. Agricultural climatic or agroclimatic data are summarized from a large number of measurements of evaporation from pans and atmometers. Certain other agroclimatic data, such as measurements of solar radiation and relative humidity, were collected at a few stations but are not analyzed in this publication.—From auth. introd.

CALIFORNIA DEPARTMENT OF WATER RESOURCES 679

1967. Vegetative water use. Resour. Agency of Calif. Bull. 113–2, 82 p., illus.

This report, the second in the Bulletin 113 series, presents current data and results on vegetative water uses; these data and results supplement and improve the material in the first report. The data and results are based on studies conducted in central and northern California. Included in the report are tables of measured pan evaporation, atmometer evaporation, and evapotranspiration data; recommended pan and atmometer evapotranspiration coefficients; recommended total evapotranspiration values; and evapotranspiration of applied water. The report also contains a discussion of the factors affecting evapotranspiration and the factors affecting estimates of irrigation requirements.—From auth. abstr.

MUNN, R. E. 680

1961. Energy budget and mass transfer theories of evaporation. *In* Symposium on Evaporation, Toronto, Canada, 1961. Canada Dep. N. Aff. and Nat. Resour., Water Resour. Br., Hydrol. Symp. Proc. [Ottawa] 2: 8-30.

A review is given of the physical principles involved in studying the energy balance of evaporating surfaces and in considering the net mass transfer of water vapor from evaporating surfaces by turbulence and molecular diffusion. The relative usefulness of the energy budget and mass transfer approaches to evaporation phenomena is discussed.—Auth. synop.

NEBRASKA WATER RESOURCES RESEARCH INSTITUTE 681

1969. Research in evapotranspiration; energy sources for evapotranspiration in the plains region. Nebr. Univ. Coll. Agr. and Home Econ. Hort. Progr. Rep. 73, 153 p., illus.

Construction began in 1966 on a lysimetric research facility at the University of Nebraska Field Laboratory at Mead, Nebr. A statistical approach to the estimation of bare soil evaporation was developed. Lysimetric data for the summer and fall of 1966 and local meteorological data published by the Weather Bureau were used. Multiple regression analysis emphasized the importance of soil-moisture deficit, solar radiation, and wind passage as the factors most closely controlling evaporation from bare soil.

Advection of sensible heat from drier regions and from dry fields adjacent to the irrigated experimental area contributes a major share of the energy consumed in the process of evapotranspiration from alfalfa in the eastern Great Plains. Since alfalfa exerts little canopy resistance when the crop is well supplied with water, the measurements of evapotranspiration are indicative of the "potential evaporation" for the region.

The Bowen-ratio energy balance method gave good agreement with lysimetrically measured evapotranspiration from alfalfa. The method fails to predict nocturnal water use, however. Aerodynamic methods, uncorrected for atmospheric stability conditions, did not estimate evapotranspiration with sufficiently good accuracy during the daytime to warrant their use.

The Penman method underestimated evapotranspiration under "potential" conditions, probably because the constants used were derived from a free water surface and do not account for the roughness of the alfalfa canopy. The rougher the crop, the more heat it will extract from the passing air when conditions of advection prevail. van Bavel's combination method gave estimates which varied greatly, as it tends to underestimate evapotranspiration on calm days and overestimate on windy days.—From auth. sum.

PACIFIC SOUTHWEST INTER-AGENCY COMMITTEE 682

1966. Limitations in hydrologic data as applied to the studies of water control and water management. Rep. of Hydrol. Subcomm. 129 p., illus. Processed.

This report discusses problems of evapotranspiration in some detail and outlines methods of measurement. The methods of measurement may be classified as water-loss methods, aerodynamic and energy-balance methods, and use of empirical formulas.

The water-loss methods include the use of evapotranspiration tanks (lysimeters), soil-water budgets, water-table fluctuations, inflow-outflow budgets, seepage runs, evapotranspiration tents, and evaporation as an index of evapotranspiration. The aerodynamic and energy-balance methods include the measurement of water vapor over a vegetated surface (atmospheric-flux and energy-budget methods). The empirical formulas discussed are those of Blaney-Criddle, Thornthwaite, Penman, Munson (1960, 508), and Lowry-Johnson (1941, 569). This article indicates the limitations or uncertainties involved in use of each method.

RIJTEMA, P. E. 683

1968. On the transfer of transpiration and crop production data to different climates. *In* Water for Peace: International Conference on Water for Peace—May 23-31, 1967. U. S. Govt. Print. Off. v. 2: 612–623.

Actual transpiration can be calculated with a combined aerodynamic and energy balance approach, taking into account the surface roughness and the geometry of the evaporation surface, as well as the stomatal diffusion resistance, in relation to light intensity and soil physical properties. The paper shows that these factors are independent of climate.

A discussion is given of the calculation of the relation between the evaporation from a wet cropped surface and from a free water surface. The proposed method is of particular importance for the transfer of empirically determined crop factors from one area to another with different climatological conditions.

Some examples are given of the relations between calculated and measured data of evapotranspiration. It appears that a reasonable agreement exists. Finally, the paper discusses limitations in knowledge of the values of the various crop factors affecting both transpiration and production.—From auth. abstr.

ROBINSON, T. W. 684

1966. Evapotranspiration losses—the status of research and problems of measurements. *In* Vegetation Management on Flood Plains and Riparian Lands. Phreatophyte Symp., Pac. Southwest Inter-Agency Comm. 66-3 Meet., Albuquerque, N. Mex., Aug. 30, 1966. p. 7–18. Processed.

This discussion was concerned with the means of determining evapotranspiration where water is nonlimiting, as in phreatophyte areas. The approaches can be grouped as follows: Direct measurement of water loss by various methods, aerodynamic and energy balance methods, and empirical formulas. All the methods are weak in one respect or another.

Evapotranspiration tank studies have provided the bulk of the usable water-loss data. Tanks must be of sufficient size to allow proper root development. The environment should be of the same species or species association to avoid the "oasis effect." Provisions must also be made to prevent dissolved solids from accumulating in the tanks.

Soil-moisture studies are not suited to the determination of evapotranspiration by phreatophytes because the plants depend on their supply from the water table rather than moisture in the soil above the capillary fringe.

Measurement of water loss by a study of the daily water table fluctuations is a simple, inexpensive, and readily adapted method under some conditions for determining evapotranspiration by phreatophytes.

The inflow-outflow budget and seepage-run methods, both developed in the Safford Valley, Ariz., are adapted to reaches of valley streams between gaging stations.

The relation of evaporation as measured by a Weather Bureau class *A* evaporation pan or by a Livingston atmometer to evapotranspiration has received considerable attention recently in California.

The evapotranspiration-tent method determined evapotranspiration as the difference in water content of the air entering and leaving a ventilated plastic tent enclosing a plant or grass plot. Temperature build-up in the tent may make a comparison of tent water losses to evapotranspiration from plants in the natural habitat very difficult.

The atmospheric flux method requires the measurement of fluctuation in water-vapor concentrations and wind speed and direction at a specified height above the vegetation.

The energy-balance method is an accounting of the incoming and outgoing thermal energy for a vegetative surface. It requires the measurement of wind speed, humidity, air temperature, incoming and reflected solar radiation (short wave), and incoming and outgoing long-wave radiation.

Three widely used formulas, the Blaney-Criddle, Thornthwaite, and Penman, are suitable for the geographic location for which they were developed. The Blaney-Criddle formula was developed in the arid Western United States for extrapolating measured values of evapotranspiration in one area to another where growth conditions are similar and where temperature records are available. The Thornthwaite formula, designed for use in the humid seaboard of the Eastern United States, also included the parameters of temperature and daytime hours but there is no consumptive use factor. Generally, it is not suited for calculating evapotranspiration by phreatophyte stands in the West because of the requirement for unlimited boundary conditions. The Penman formula, developed in England, is more complex and requires more meteorological data than either of the others. The data required are duration of bright sunshine, temperature, humidity, and wind speed.—From auth. sum.

TANNER, C. B. 685

1966. Comparison of energy balance and mass transport methods for measuring evaporation. *In* Evapotranspiration and Its Role in

Water Resources Management. Amer. Soc. Agr. Eng. Conf. Proc., Chicago, Ill., Dec. 5-6, 1966. Amer. Soc. Agr. Eng., St. Joseph, Mich. p. 45–48.

This comparison of energy-balance and mass-transport methods relates only to their relative convenience and accuracy for determining evaporation —the flux of vapor from the earth's surface. It is not concerned with the relative merits of the two methods for determining transfer coefficients or for studying turbulent transport principles.

Either the profile or the energy-balance methods will, over relatively homogeneous surfaces, provide data which are as accurate as needed for most engineering purposes. Micrometeorological methods are, with use of the lysimeter, the only methods which are available to measure evaporation over short periods of time. Lysimetry has important problems regarding sampling. Lysimetry must be large in comparison with the scale of inhomogeneity of the vegetation, must have some form of moisture control, and must meet several other detailed requirements for hourly and daily measurements.

If these complicated, rational methods appear burdened with difficulty when compared to the more convenient empirical methods commonly used by engineers, there is a good reason why this is so. When someone selects an empirical method, he makes the tacit assumption that he is concerned primarily with long-period estimates, that the method need not be based on fundamental principles, and that reliability is dispensable. Empirical methods can be used for long-period estimates when calibrated against measurement in a given region but can provide only a guess unless they have been previously calibrated. Without calibration, empirical estimates are not reliable; however, they are cloaked with the trappings of measurement, which apparently have professional value.—From auth. sum.

WARD, R. C. 686

1971. Measuring evapotranspiration: A review. J. Hydrol. [Amsterdam] 13: 1–21.

Recent work has improved the possibility of calculating the evaporative water loss from a natural, vegetated surface, and the most significant contributions are reviewed in the present paper. Potential evapotranspiration is defined and the validity of this concept is carefully examined. The paper then discusses the principal approaches to the measurement of potential evapotranspiration, i.e. the transformation of measurements made from non-vegetated surfaces, the direct measurement of water losses from moist vegetated surfaces, and more or less empirical formulae, and to the measurement of actual evapotranspiration, i.e. theoretical modelling of the evapotranspiration process, physical modelling of the evapotranspiration system and the measurement of moisture flux above the evaporating surface.—Auth. abstr.

See also 1, 8, 19, 23, 364.

APPLICATION TO LARGER UNITS

COMPUTATION OF POTENTIAL EVAPOTRANSPIRATION

ARKLEY, RODNEY J., AND ULRICH, RUDOLPH 687

1962. The use of calculated actual and potential evapotranspiration for estimating potential plant growth. Hilgardia 32(10): 443–462, illus.

Potential evaporation (ET_p) can readily be calculated from monthly mean temperatures by means of tables and nomograms available in the literature. Actual evapotranspiration (ET_a) is calculated from ET_p by taking precipita-

tion and the water-holding capacity of the soil into account. Either value can be calculated for the whole year (ET_p or ET_a) if frost-tolerant plants are under consideration or for the frost-free period (ET_p 32° or ET_a 32°) if frost-sensitive plants are under consideration.

All four values—ET_p, ET_a, ET_p 32°, ET_a 32°— were calculated for 211 California stations and for 27 Nevada and Oregon stations near California. Plotting these values for 25 stations along a traverse through central California and western Nevada reveals great differences from coast to inland stations and from low to high altitudes. Comparison of the values with natural vegetation and with crops in the different regions indicates that the values are useful as indexes of expected growth of cultivated crops, range, and forest. ET_p values are useful if moisture is not limiting, as in humid climates or where irrigation water is available; ET_a values are useful for predicting the suitability of a climate for dry-farmed crops, for estimating the potential for increased growth obtainable by irrigation, and for more precise studies of the effects of climate on natural vegetation. The indexes, used together, can be helpful in crop selection and other soil-management decisions.

Isograms of the four *ET* values, based on all California stations and plotted on maps of the State, furnish much information about those climatic limitations on plant growth that involve moisture and temperature relations. —Auth. abstr.

BUOL, S. W. 688

1964. Calculated actual and potential evapotranspiration in Arizona. Ariz. Agr. Exp. Sta. Tech. Bull. 162, 48 p., illus.

By use of the Thornthwaite formulas as incorporated in the nomograms by Palmer and Havens (1958, 524), potential evapotranspiration for the full year and for the 32° F. frost-free season were computed for 61 weather stations in Arizona. For comparison, the actual evapotranspiration values were computed for the year, the 32° F. frost-free season, the 28° F. frost-free season, and the 24° F. frost-free season.

Isograms of the calculated actual and potential evapotranspiration were plotted for the year and for the 32° F. frost-free season.

The publication includes maps that point out areas of the State in which, climatically, it is possible to grow various crops and that give parameters of meteorological measurements for comparison with the distribution of natural vegetation.

MATHER, J. R. 689

1964. Average climatic water balance data of the continents. Part 7, United States. Drexel Inst. of Tech. Lab. of Climatol. Pub. in Climatol. 17(3): 419–615.

The average potential evapotranspiration by months for many locations in the United States was computed by the Thornthwaite method. Other parts include such information for other areas of the world.

PATRIC, JAMES H., AND BLACK, PETER E. 690

1968. Potential evapotranspiration and climate in Alaska by Thornthwaite's classification. U. S. Dep. Agr. Forest Serv. Pacific Northwest Forest and Range Exp. Sta. Res. Pap. PNW-71, 28 pp., illus.

Estimates and measurements of potential evapotranspiration determined by Thornthwaite's methods showed good agreement with estimates and measurements made by other methods. Distribution of vegetation in the interior of Alaska seems to be governed more by temperature than by availability of moisture.

RAMDAS, L. A. 691
1957. Evaporation and potential evapo-transpiration over the Indian sub-continent. Indian J. Agr. Sci. [New Delhi] 27(2): 137–149.

This article discusses briefly the spatial distribution of (*a*) the mean annual evaporation and (*b*) the mean annual potential evapotranspiration over the subcontinent of India. Potential evapotranspiration may be estimated according to a new, simple technique developed by the author. A chart for India so prepared shows significant departures from a chart recently published by Thornthwaite and co-workers.—From auth. abstr.

See also 651.

WATER REQUIREMENTS FOR IRRIGATED AREAS

BLANEY, HARRY F., AND CRIDDLE, WAYNE D. 692
1949. Consumptive use of water in the irrigated areas of the Upper Colorado River Basin. Provisional. U. S. Dep. Agr., Soil Conserv. Serv. 49 p., illus. Processed.

BLANEY, HARRY F., AND CRIDDLE, WAYNE D. 693
1949. Consumptive use and irrigation water requirements of crops in Colorado. U. S. Dep. Agr., Soil Conserv. Serv. 55 p. Processed.

BLANEY, HARRY F., AND HANSON, ELDON G. 694
1965. Consumptive use and water requirements in New Mexico. N. Mex. State Eng. Tech. Rep. 32, 82 p., illus.

CRIDDLE, WAYNE D. 695
1952. Consumptive use of water. Irrigated crops. Amer. Soc. Civil Eng. Trans. 117: 991–1003, illus.

CRIDDLE, WAYNE D., HARRIS, KARL, AND WILLARDSON, LYMAN S. 696
1962. Consumptive use and water requirements for Utah. Utah Off. State Eng. Tech. Publ. 8, 47 p., illus.

DAVIS, STERLING, EVANS, NORMAN A., AND HAZEN, ARLON G. 697
1952. Estimates of irrigation water requirements for crops in North Dakota. N. Dak. Agr. Exp. Sta. Bull. 377, 18 p., illus.

DILLMAN, ARTHUR C. 698
1931. The water requirement of certain crop plants and weeds in the northern Great Plains. J. Agr. Res. 42(4): 187–238, illus.

ERIE, L. J., FRENCH, ORRIN F., AND HARRIS, KARL 699
1965. Consumptive use of water by crops in Arizona. Ariz. Agr. Exp. Sta. Tech. Bull. 169, 44 p., illus.

FORTIER, SAMUEL 700
1927. Orchard irrigation. U. S. Dep. Agr. Farmers' Bull. 1518, 27 p., illus.

FORTIER, SAMUEL, AND YOUNG, ARTHUR A. 701
1930. Irrigation requirements of arid and semiarid lands of the Southwest. U. S. Dep. Agr. Tech. Bull. 185, 69 p., illus.

GARTON, JAMES E., AND CRIDDLE, WAYNE D. 702
1955. Estimates of consumptive-use and irrigation water requirements of crops in Oklahoma. Okla. Agr. Exp. Sta. Tech. Bull. T-57, 26 p., illus.

HANSON, RICHARD E., AND MEYER, WALTER R. 703
1953. Irrigation requirements, estimates for Kansas. Kans. Eng. Exp. Sta. Bull. 69, 24 p., illus.

HARROLD, LLOYD L. 704
1955. Evapotranspiration rates for various crops. Agr. Eng. 36(10): 669–672, illus.

HOUSTON, CLYDE E. 705
1955. Consumptive use of water by alfalfa in western Nevada. Nev. Agr. Exp. Sta. Bull. 191, 20 p., illus.

JENSEN, MAX C., AND CRIDDLE, WAYNE D. 706
1952. Estimated irrigation water requirements for Idaho. Idaho Agr. Exp. Sta. Bull. 291, 23 p.

MCDANIELS, LOUIS L. 707
1960. Consumptive use of water by major crops in Texas. Tex. Bd. Water Eng. Bull. 6019, 47 p.

MOLENAAR, ALDERT, CRIDDLE, WAYNE D., AND PAIRE, CLAUDE H. 708
1952. Estimates of consumptive use and irrigation requirements of crops in Washington. Wash. Agr. Exp. Sta. Circ. 201, 20 p., illus.

MONSON, O. W., CRIDDLE, WAYNE D., AND DAVIS, STERLING 709
1953. Estimated water requirements of crops in irrigated areas of Montana. Mont. Agr. Exp. Sta. Bull. 494, 23 p., illus.

SCHLEUSENER, P. E., NEMETHY, J. J., SHULL, H. H., AND WILLIAMS, G. E. 710
1961. Pasture irrigation requirements calculated from climatological data. Amer. Soc. Agr. Eng. Trans. 4(1): 6–7, 11.

TILESTON, FRED M., AND WOLFE, JOHN W. 711
1951. Irrigation requirements (estimates for Oregon). Oreg. Agr. Exp. Sta. Bull. 500, 32 p., illus.

TOMLINSON, BYRON R. 712
1951. Estimate of water requirements of crops. Wyo. Agr. Exp. Sta. Bull. 303, 28 p.

YOUNG, ARTHUR A. 713
1945. Irrigation requirements of California crops. Calif. Dep. Public Works Div. Water Resour. Bull. 51, 132 p., illus.

ABBREVIATIONS USED IN IDENTIFYING PUBLICATIONS

Acta Agr. Scan. [Stockholm]	Acta Agriculturae Scandinavica. Stockholm, Sweden.
Agr. Eng.	Agricultural Engineering. St. Joseph, Mich.
Agr. Meteorol. [Amsterdam]	Agricultural Meteorology. Amsterdam, The Netherlands.
Agron. J.	Agronomy Journal. Madison, Wis.

Akad. Nauk SSSR. Geofiz. Inst. Tr. [Moscow]	Akademiya Nauk SSSR. Geofizicheskiy Institut. Trudy. Moscow, Russia
Amer. Ass. Advance. Sci. Pub.	American Association for the Advancement of Science. Publication. Washington, D. C.
Amer. Geophys. Union Trans.	American Geophysical Union. Transactions. Washington, D. C.
Amer. J. Bot.	American Journal of Botany. Lancaster, Pa.
Amer. Nat.	American Naturalist. Lancaster, Pa.
Amer. Soc. Agr. Eng. Trans.	American Society of Agricultural Engineers. Transactions of ASAE. St. Joseph, Mich.
Amer. Soc. Civil Eng.	American Society of Civil Engineers. New York, N. Y.
Proc.	Proceedings.
J. Hydraul. Div.	Journal of the Hydraulics Division
J. Irrig. and Drainage Div.	Journal of the Irrigation and Drainage Division.
Trans.	Transactions.
Ann. Agron. [Paris]	Annales Agronomiques. Paris, France.
Ann. Bot. [London]	Annals of Botany. London, England.
Annu. Rev. Plant Phys.	Annual Review of Plant Physiology. Palo Alto, Calif.
Ariz. Agr. Exp. Sta. Tech. Bull.	Arizona Agricultural Experiment Station. Technical Bulletin. Tucson, Ariz.
Ariz. Watershed Symp. Annu. Proc.	Arizona Watershed Symposium. Annual Proceedings. (Various) Phoenix, Ariz.
Aust. C.S.I.R.O. Div. Land Res. Tech. Pap. [Melbourne]	[Australia] Commonwealth Scientific and Industrial Research Organization. Division of Land Research and Regional Survey. Technical Paper. Melbourne, Australia.
Aust. C.S.I.R.O. Div. Meteorol. Phys. Tech. Pap.	[Australia] Commonwealth Scientific and Industrial Research Organization. Division of Meteorology and Physics. Technical Paper. Melbourne, Australia.
Aust. Inst. Agr. Sci. J. [Sidney]	Australian Institute of Agricultural Science. Journal. Sidney, Australia.
Aust. J. Agr. Res. [Melbourne]	Australian Journal of Agricultural Research. Melbourne, Australia.
Bot. Gaz.	Botanical Gazette. Chicago, Ill.

Bot. Rev.	Botanical Review. Lancaster, Pa.
Bot. Zeitg. [Leipzig]	Botanische Zeitung. Leipzig, Germany.
Calif. Dep. Public Works Div. Water Resour. Bull.	California Department of Public Works, Division of Water Resources. Bulletin. Sacramento, Calif.
Calif. Fish and Game.	California Fish and Game. San Francisco, Calif.
Calif. Univ. Davis Dep. Irrig. Annu. Rep.	California, University of, Department of Irrigation. Annual Report. Davis, Calif.
Calif. Univ. Davis Dept. Water Sci. and Eng. Pap.	California, University of, Department of Water Science and Engineering. Paper. Davis, Calif.
Cambridge Phil. Soc. Biol. Rev. [London].	Cambridge Philosophical Society. Biological Reviews. London, England.
Can. Dep. Energy Mines and Resour. Geol. Surv. Can. Bull. [Ottawa].	[Canada] Department of Energy, Mines and Resources. Geological Survey of Canada. Bulletin. Ottawa, Canada.
Can. Dep. N. Aff. and Nat. Resour. Water Resour. Br. Hydrol. Symp. Proc. [Ottawa].	[Canada] Department of Northern Affairs and National Resources, Water Resource Branch. Hydrology Symposium Proceedings. Ottawa, Canada.
Can. J. Plant Sci. [Ottawa]	Canadian Journal of Plant Science. Ottawa, Canada.
Can. J. Res. [Ottawa]	Canadian Journal of Research. Ottawa, Canada.
Colo. State Univ. Hydrol. Pap.	Colorado State University. Hydrology Paper. Ft. Collins, Colo.
Drexel Inst. of Tech. Lab. of Climatol. Pub. in Climatol.	Drexel Institute of Technology, Laboratory of Climatology, Publication in Climatology, Centerton, N. J.
Diss. Abstr.	Dissertation Abstracts. Section B, Science and Engineering. Ann Arbor, Mich.
Ecol. Monogr.	Ecological Monographs. Durham, S. C.
Ecology	Ecology. Durham, S. C.
Empire J. Exp. Agr. [London]	Empire Journal Experimental Agriculture. London, England.
Eng. News–Rec.	Engineering News–Record. New York, N. Y.
Exp. Agr. [London–New York]	Experimental Agriculture. London, England, and New York, N. Y.
Forest Sci.	Forest Science. Washington, D. C.
Forest. in S. Afr. [Pretoria]	Forestry in South Africa. Pretoria, Republic of South Africa.

Forsch. Geb. Agr.–Phys. [Heidelberg]	Forschungen auf dem Gebiete der Agrikultur–Physik. Heidelberg, Republic of Germany.
Geogr. Rev.	Geographical Review. New York, N. Y.
Germany Deutschen Wetterd. Ber. [Bad Kissingen]	[Germany, Federal Republic of] Deutschen Wetterdienstes. Berichte. Bad Kissengen, Federal Republic of Germany.
Germany Deutschen Wetterd. U. S. Zone. Ber. [Bad Kissingen]	[Germany, Federal Republic of] Deutschen Wetterdienstes in der U. S. Zone. Berichte. Bad Kissengen, Federal Republic of Germany.
Germany Deutschen Wetterd. Mitt. [Bad Kissingen]	[Germany, Federal Republic of] Deutschen Wetterdienstes. Mitteilungen. Bad Kissengen, Federal Republic of Germany.
Gidrometeorol. izdatel'stvo [Leningrad]	Gidrometeorologicheskoe izdatel'stvo. Leningrad, Russia.
Hilgardia	Hilgardia. Berkeley, Calif.
Idaho Agr. Exp. Sta. Bull.	Idaho Agricultural Experiment Station. Bulletin. Moscow, Idaho.
Ill. Agr. Exp. Sta. Forest. Note	Illinois Agricultural Experiment Station. Forestry Note. Urbana, Ill.
India Dep. Agr. Chem. Ser. [Calcutta and London]	[India] Department of Agriculture in India. Chemical Series. Calcutta, India and London, England.
Indian J. Agr. Sci. [New Delhi]	Indian Journal of Agricultural Science. New Delhi, India.
Inst. Water Eng. J. [London]	Institute of Water Engineering. Journal. London, England.
Int. Ass. Sci. Hydrol. Bull. [Louvain]	International Association of Scientific Hydrology. Bulletin. Louvain, Belgium.
Int. Ass. Sci. Hydrol. Pub. [Gentbrugge]	International Association of Scientific Hydrology. International Union of Geodesy and Geophysics. Symposium Proceedings. (Various locations). Publication. Gentbrugge, Belgium.
Int. Cong. Soil Sci. Trans. [Amsterdam]	International Congress of Soil Science. Transactions. International Society of Soil Science. [Amsterdam, The Netherlands].
Int. J. Biometeorol. [Canberra]	International Journal of Biometeorology. Canberra, Australia.

Int. Rev. Forest. Res.	International Review of Forestry Research. New York, N. Y.
Int. Union Forest. Res. Organ.	International Union of Forestry Research Organizations.
Israel J. Agr. Res. [Rehovot]	Israel Journal of Agricultural Research. Rehovot, Israel.
Israel Res. Counc. Bull. [Jerusalem]	Israel, Research Council of. Bulletin. Jerusalem, Israel.
Jap. Forest. Soc. J. [Tokyo]	Japanese Forestry Society. Journal. Tokyo, Japan.
The Johns Hopkins Univ. Lab. of Climatol. Pub. in Climatol.	The Johns Hopkins University. Laboratory of Climatology. Publications in Climatology. Seabrook, N. J.
J. Agr. Eng. Res. [Silsoe]	Journal of Agricultural Engineering Research. Silsoe, England.
J. Agr. Res.	Journal of Agricultural Research, Washington, D.C.
J. Agr. Sci. [London]	Journal of Agricultural Science, London, England.
J. Appl. Ecol. [Oxford]	Journal of Applied Ecology. Oxford, England.
J. Appl. Meteorol.	Journal of Applied Meteorology. Boston, Mass.
J. Atmos. Sci.	Journal Atmospheric Sciences. Boston, Mass.
J. Ecol. [London]	Journal Ecology. London, England.
J. Forest.	Journal of Forestry. Washington, D. C.
J. Geophys. Res.	Journal of Geophysical Research. Richmond, Va.
J. Hydrol. [Amsterdam]	Journal of Hydrology. Amsterdam, The Netherlands.
J. Meteorol.	Journal of Meteorology. Lancaster, Pa.
J. Range Manage.	Journal of Range Management. Denver, Colo.
J. Soil Sci. [Oxford]	Journal of Soil Science. Oxford, England.
J. Soil Water Conserv.	Journal of Soil and Water Conservation. Ankeny, Iowa.
J. S. Afr. Forest. Ass. [Johannesburg]	Journal of the South African Forestry Association. Johannesburg, South Africa.
Kans. Eng. Exp. Sta. Bull.	Kansas Engineering Experiment Station. Bulletin. Manhattan, Kans.
Meteorol. Monogr.	Meteorological Monographs. American Meteorological Society. Boston, Mass.
Minn. Acad. Sci. Proc.	Minnesota Academy of Science. Proceedings.
Mont. Agr. Exp. Sta. Bull.	Montana Agricultural Experiment Station. Bulletin. Bozeman, Mont.

Mon. Weather Rev.	Monthly Weather Review. Washington, D. C.
Nat. Acad. Sci. Proc.	National Academy of Sciences. Proceedings. Washington, D.C.
Nature [London]	Nature. London, England.
Nebr. Agr. Exp. Sta. Res. Bull.	Nebraska Agricultural Experiment Station. Research Bulletin. Lincoln, Nebr.
Nebr. Univ. Coll. Agr. and Home Econ. Hort. Progr. Rep.	Nebraska, University of, College of Agriculture and Home Economics. Horticulture Progress Report. Lincoln, Nebr.
Neth. J. Agr. Sci. [Wageningen]	Netherlands Journal of Agricultural Science. Wageningen, The Netherlands.
Nev. Agr. Exp. Sta. Bull.	Nevada Agricultural Experiment Station. Bulletin. Reno, Nev.
N. Mex. Inst. of Mining and Tech. Prof. Pap.	New Mexico Institute of Mining and Technology. Professional Paper. Socorro, N. Mex.
N. Mex. State Eng. Tech. Rep.	New Mexico State Engineer. Technical Report. Santa Fe, N. Mex.
New Phytol. [London]	New Phytologist. London, England.
N. Zealand J. Sci. [Wellington]	New Zealand Journal of Science. Wellington, New Zealand.
N. Dak. Agr. Exp. Sta. Bull.	North Dakota Agricultural Experiment Station. Bulletin. Fargo, N. Dak.
Oecol. Planatarum [Paris]	Oecologia Planatarum. Gauthier Villars. Paris, France.
Ohio. J. Sci.	Ohio Journal of Science. Columbus, Ohio.
Okla. Agr. Exp. Sta. Tech. Bull.	Oklahoma Agricultural Experiment Station. Technical Bulletin. Stillwater, Okla.
Oreg. Agr. Exp. Sta. Bull.	Oregon Agricultural Experiment Station. Bulletin. Corvallis, Oreg.
Palest. J. Bot. Rehovot Ser.	Palestine Journal of Botany. Rehovot Series. Rehovot, Israel.
Phys. Rev.	Physical Review. New York, N. Y.
Physiol. Plant. [Copenhagen]	Physiologia Planetarum. Copenhagen, Denmark.
Phyton [Vicente Lopez]	Phyton. Vicente Lopez, Argentina.
Plant and Cell Physiol. [Tokyo]	Plant and Cell Physiology. Tokyo, Japan.
Plant Physiol.	Plant Physiology. Lancaster, Pa.
Plant World	Plant World. Baltimore, Md.
Progr. Agr. in Ariz.	Progressive Agriculture in Arizona. Tucson, Ariz.

Resour. Agency of Calif. Bull.	The Resource Agency of California. Bulletin. Department of Water Resources. Sacramento, Calif.
Roy. Coll. Sci. J. [London]	Royal College of Science. Journal. London, England.
Roy. Meteorol. Soc. Quart. J. [London]	Royal Meteorological Society. Quarterly Journal. London, England.
Roy. Soc. Proc. Ser. A [London]	Royal Society. Proceedings. Series A, Mathematical and Physical Sciences. London, England.
Schweiz. Anst. Forstl. Versuchsw. Mitt. [Zurich]	Schweizerische Anstalt fur das Forstliche Versuchswesen. Mitteilungen. Zurich, Switzerland.
Science	Science. Lancaster, Pa.
Sci. Agr. [Ottawa]	Scientific Agriculture. Ottawa, Canada.
Selec. Water Resour. Abstr.	Selected Water Resources Abstracts. Water Resources Scientific Information Center. U. S. Department of the Interior. Washington, D. C.
Sigma Xi Quart.	Sigma Xi Quarterly. New Haven, Conn.
Soc. Exp. Biol. Symp. [London]	Society of Experimental Biology, Symposia. London, England.
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